JOURNAL OF

GENERAL CHEMISTRY

OF THE USSR

(ZHURNAL OBSHCHEI KHIMII)

IN ENGLISH TRANSLATION
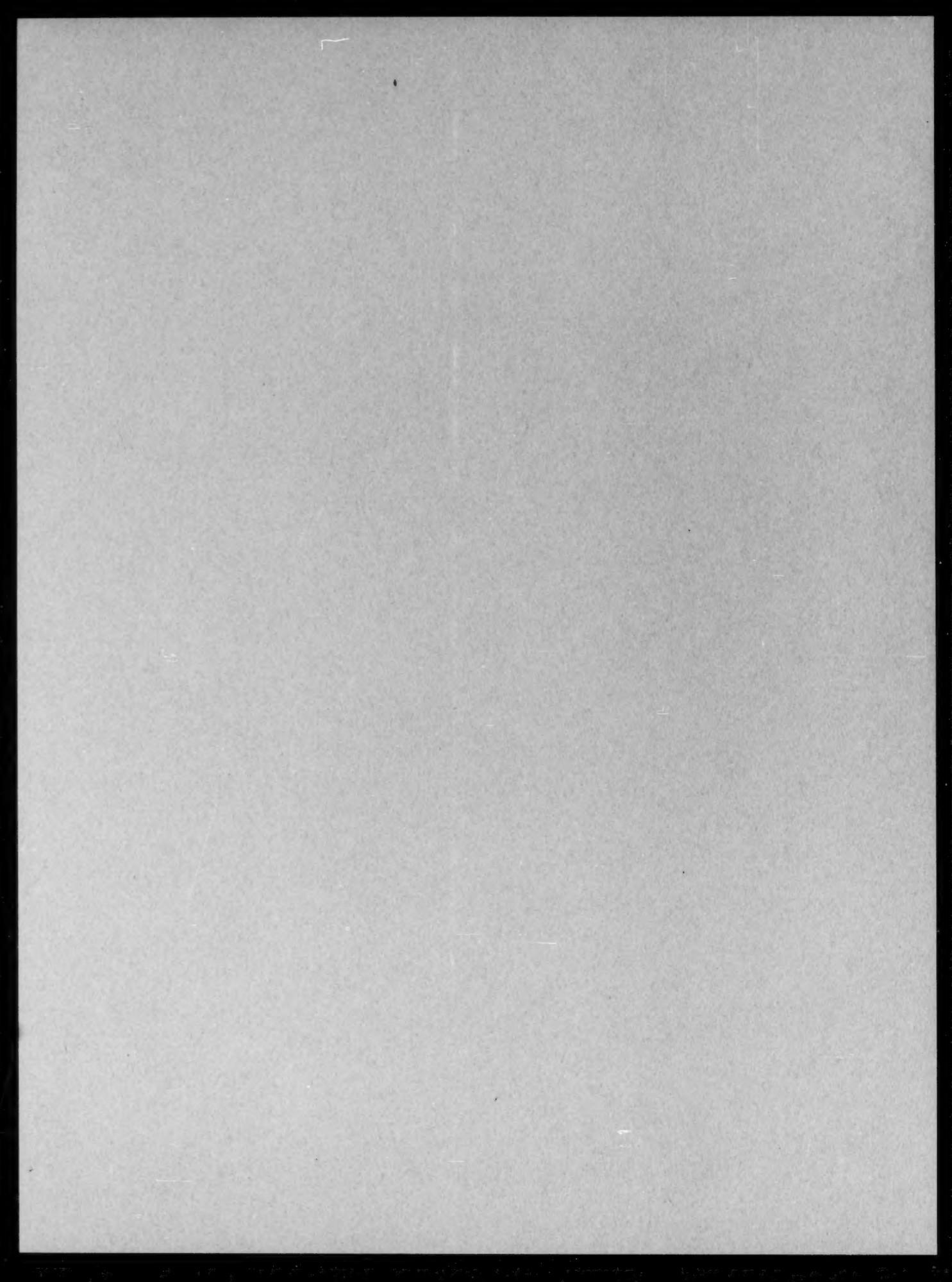
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A publication of the Academy of Sciences of the USSR

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THERMOCHEMISTRY OF ELECTROLYTE SOLUTIONS

V. INTEGRAL HEATS OF SOLUTION OF NaCl and MgCl$_2$ · 6H$_2$O IN WATER AT TEMPERATURES OF +2 AND −6°

K. P. Mishchenko and I. F. Yakovlev

Lensoviet Technological Institute, Leningrad

Original article submitted June 9, 1958

The thermochemical study of aqueous solutions of electrolytes over a wide range of concentrations and temperatures is of essential interest both in developing the theory of solutions and in certain branches of industry. The polytherms of the integral heats of solution, thermal capacity, and partial molal derivatives of these values obtained, coupled with other data, make it possible to characterize in more detail the nature of electrolyte solutions and, in particular, to elucidate the role of the solvent in the formation of the solution. For aqueous solutions, this role is most prominently expressed at temperatures close to and below 0°, since, in this case, the thermal motion has the least disrupting effect on the primary structure of the water, and the interaction between ions and solvent must appear most clearly under these conditions.

EXPERIMENTAL

The exceptional paucity and inconsistency of energy characteristics of water—salt solutions close to 0° [1 to 4] compelled us to extend investigations in this field. For this purpose, we planned and made two low-temperature calorimeters [5], which made it possible to measure integral heats of solution with an accuracy of ± 0.3%. By means of these apparatuses, we studied, at +2 and −6°, the integral heats of solution in water of NaCl and MgCl$_2$ · 6H$_2$O over a wide range of concentrations, and also at several concentrations of MgCl$_2$. The latter measurements made it possible to calculate the heat effect of MgCl$_2$ · 6H$_2$O formation from anhydrous salt and water at +2 and −6°, and thus convert to the isotherms of the integral heats of solution of MgCl$_2$ at these temperatures. We described the measurement technique previously [5,6].

The experimental data obtained are presented in Tables 1-3.

We should note that there are no values at all in the literature for the integral heats of solution for aqueous solutions of strong electrolytes at temperatures below 0° and, as far as we know, we are the first to make such measurements.

Measurements at temperatures below the crystallization point of water involved certain difficulties. First of all, under these conditions, it was impossible to dissolve the salt directly in water or to dilute a prepared stable solution with water. Solution of the crystalline salt in a stable liquid solution gave us only intermediate heats of solution, and to obtain ΔH_m from them we had to have at least one value of the integral heat of solution at the given temperature. This value can only be obtained by converting values of ΔH_m measured at a higher temperature to −6°, by means of Kirchhoff's equation. For this conversion, we used the temperature dependences of the heat capacities of crystalline salts for NaCl [7] and for MgCl$_2$ · 6H$_2$O [8]. We measured the heat capacity of the corresponding solutions, and the heat capacity of pure water was calculated by Bartoli and Stracciati's equation [9].

On the basis of these data, we calculated ΔH_m at −6° for each salt from one basic value, and using the heats of dilution or concentration of stable solutions at the same temperature, we constructed all the isotherms of ΔH_m at −6°.

TABLE 1[*]

Integral Heats of Solution of NaCl in Water at +2 and −6°

$m = \dfrac{\text{mole NaCl}}{1000\,\text{g H}_2\text{O}}$	$\Delta H_m \left(\dfrac{\text{cal}}{\text{mole}}\right)$	Notes
	Temperature +2°	
0.0624	1846	
0.1248	1817	
0.2001	1780	Average value of ΔH_m, each from three
0.3005	1706	direct solution experiments.
0.4003	1650	
0.5002	1632	
0.7504	1531	
1.0058	1439	
1.4395	1303	Average value of ΔH_m, each from two measure-
1.9457	1187	ments of the intermediate heats of solution
2.5017	1035	
3.1064	946	
3.6363	839	
4.0012	767	
4.5586	680	Average value of ΔH_m, each from two
4.9966	619	measurements of the heats of dilution.
5.3569	534	
6.0004	454	
	Temperature −6°	
2.5294	1211	Calculated from Kirchhoff's equation.
3.0004	1075	
3.5017	949	Average value of ΔH_m, each from two
4.0152	838	measurements of the intermediate
4.6000	732	heats of solution.
4.0012	856	Average value of ΔH_m, each from three
5.0012	693	measurements of the heat of dilution.

TABLE 2

Integral Heats of Solution of MgCl$_2$ · 6H$_2$O in Water at +2 and −6°

$m = \dfrac{\text{mole MgCl}_2}{1000\,\text{g H}_2\text{O}}$	$\Delta H_m \left(\dfrac{\text{cal}}{\text{mole}}\right)$	Notes
	Temperature +2°	
0.0472	−2484	Average value of ΔH_m, each from three
0.1004	−2450	direct solution measurements.
0.2306	−2404	
0.4064	−2336	
0.6140	−2272	
0.8260	−2206	
1.0645	−2143	Average value of ΔH_m, each from three
1.2960	−2076	measurements of the intermediate heats
1.5015	−2011	of solution.
1.7170	−1934	
1.9163	−1854	

[*] As in all work from our laboratory, the "minus" sign corresponds here to the liberation, and the "plus" sign to the absorption, of heat.

TABLE 2 (continued)

$m = \dfrac{\text{mole } MgCl_2}{1000 \text{ g } H_2O}$	$\Delta H_m \left(\dfrac{cal}{mole} \right)$	Notes
2.3704	−1634	
2.8017	−1334	
3.4496	− 952	Average value of ΔH_m, each from three
4.0069	− 602	repeated dilution experiments.
4.6144	− 305	
4.8463	+ 10	
5.4515	+ 572	

Temperature −6°

1.5890	−1168	Calculated from Kirchhoff's equation
1.7672	−1153	
1.7719	−1163	
1.9365	−1145	
1.9431	−1160	
2.1132	−1150	
2.1351	−1149	
2.3140	−1103	
2.2824	−1124	
2.4895	−1066	
2.4178	−1098	
2.5836	−1063	Values of ΔH_m from intermediate heats
2.7223	−1001	of solution.
2.7434	−1012	
2.9002	− 955	
2.9254	− 943	
3.1068	− 883	
3.2874	− 810	
3.4100	− 707	
3.6084	− 630	
3.7676	− 540	
3.9312	− 440	
4.0718	− 361	
4.5222	− 126	Average value of ΔH_m from two measurements of the heats of dilution.

TABLE 3

Integral Heats of Solution of Anhydrous $MgCl_2$ in Water at +2 and −6°

Temperature	$m = \dfrac{\text{mole } MgCl_2}{1000 \text{ g } H_2O}$	$\Delta H_m \left(\dfrac{cal}{mole} \right)$
+2°	0.0425	−35662
−6	1.4811	−33970

...

In connection with the fact that we were forced to obtain the integral heats of solution from the heats of dilution of more concentrated solutions by less concentrated ones, we put forward a simple method of calculating them by means of the following thermodynamic cycle:
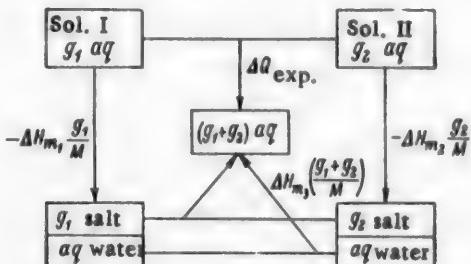
TABLE 4

Relative Partial Molal Enthalpies of NaCl and H_2O in Aqueous Solutions of NaCl, Calculated from Our Data at +2 and −6°, the Data of Scholz [2] and Lehtonen at 0° [4], and of N. K. Voskresenskaya and G. N. Yankovskaya at 50° [10], and Presented by Wüst and Lange at 25° [11]

$m = \dfrac{\text{mol. NaCl}}{1000\,\text{g } H_2O}$	$\bar{L}_1 = \dfrac{m\sqrt{m}}{2 \cdot 55.508} \cdot \dfrac{d\Delta H_m}{d\sqrt{m}}$					$\bar{L}_2 = -\Delta H_m - \dfrac{\sqrt{m}}{2} \cdot \dfrac{d\Delta H_m}{d\sqrt{m}}$				
	−6°	0°	+2°	+25°	+50°	−6°	0°	+2°	+25°	+50°
0.1	—	0.1	0.3	0	—	—	− 648	− 641	+102	—
0.2	—	0.3	0.3	0.1	—	—	− 678	− 606	+ 90	—
0.3	—	0.6	0.5	0.2	—	—	− 769	− 680	+ 62	—
0.4	—	1.2	0.8	0.4	—	—	− 859	− 741	+ 28	—
0.5	—	2	1.9	0.7	—	—	− 953	− 883	− 10	+151
0.6	—	2.7	2.8	1	—	—	−1022	− 968	− 48	+151
0.7	—	3.4	3.5	1.5	—	—	−1082	−1024	− 85	+151
0.8	—	4.5	4.3	2	—	—	−1164	−1079	−120	+151
0.9	—	5.8	5.1	2.6	—	—	−1254	−1129	−156	+151
1	—	7.2	5.9	3.1	—	—	−1334	−1181	−188	+151
1.5	—	13.3	11	5.7	—	—	−1593	−1412	−343	+ 63
2	22.4	20.4	16.8	10.2	22.4	−2100	−1839	−1594	−466	− 45
2.5	31.3	28.4	23.5	14.2	31.3	−2313	−2026	−1765	−556	− 77
3	41.1	37.4	30.9	15.2	41.1	−2511	−2204	−1930	−626	+ 54
3.5	51.8	47.1	38.9	20	51.8	−2700	−2374	−2050	−671	+171
4	63.3	57.6	47.6	21.2	63.3	−2865	−2548	−2185	−688	+153
4.5	75.6	—	56.5	21.9	75.6	−3015	—	−2305	−683	+150
5	84.6	—	63.5	21.5	86.4	−3141	—	−2434	−656	+137
5.5	—	—	76.7	17.4	—	—	—	−2550	−620	—
6	—	—	87.3	19.8	—	—	—	−2633	−570	—

TABLE 5

Relative Partial Molal Enthalpies of $MgCl_2$ and H_2O in Solutions of $MgCl_2$ in Water, Calculated from Our Data at +2 and −6°, and the Measurements of Yu. Ya. Kaganovich at 25° [12]

$m = \dfrac{\text{mol. } MgCl_2}{1000\,\text{g } H_2O}$	$\bar{L}_1 = \dfrac{m\sqrt{m}}{2 \cdot 55.508} \cdot \dfrac{d\Delta H_m}{d\sqrt{m}}$			$\bar{L}_2 = -\Delta H_m - \dfrac{\sqrt{m}}{2} \dfrac{d\Delta H_m}{d\sqrt{m}}$		
	−6°	+2°	+25°	−6°	+2°	+25°
0.2	—	− 0.3	− 1.5	—	661	870
0.4	—	− 1	− 2.3	—	805	1155
0.6	—	− 1.9	− 4.1	—	905	1385
0.8	—	− 3.4	− 10.4	—	1024	1620
1.0	—	− 5.5	− 12.8	—	1153	1845
1.5	− 1.3	− 12.7	− 26.5	1071	1442	2430
2.0	− 4.7	− 34	− 44.6	1175	2131	3090
2.5	− 23.9	−69.3	− 74.6	1644	3011	3915
3.0	− 71.3	−98.2	−120.1	2600	3594	4725
3.5	−113.9	−137.7	−164.9	3322	4271	5625
4.0	−175.2	−187.5	−240.3	4224	5004	6585
4.5	−226.6	−273.8	−320.2	4888	6129	7560
5.0	—	−375.3	−420.1	—	7499	8520
5.5	—	−453.5	−495.2	—	8219	9375

hence,

$$-\Delta H_{m1}\frac{g_1}{M} - \Delta H_{m2}\frac{g_2}{M} + \Delta H_{m3}\left(\frac{g_1 + g_2}{M}\right) = \Delta Q_{\text{expt.}} .$$
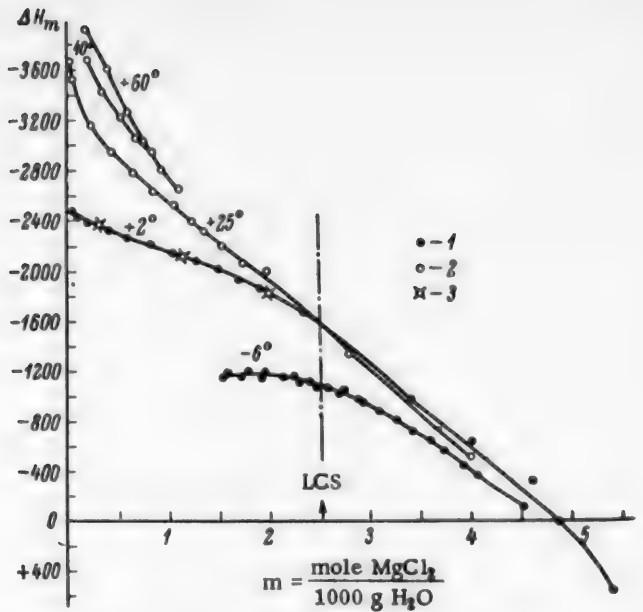
Fig. 1. Isotherms of the integral heats of solution of $MgCl_2$ in water at various temperatures: 1) our data; 2) data of Kaganovich and Mishchenko; 3) data of Winkelmann (close to 0°).
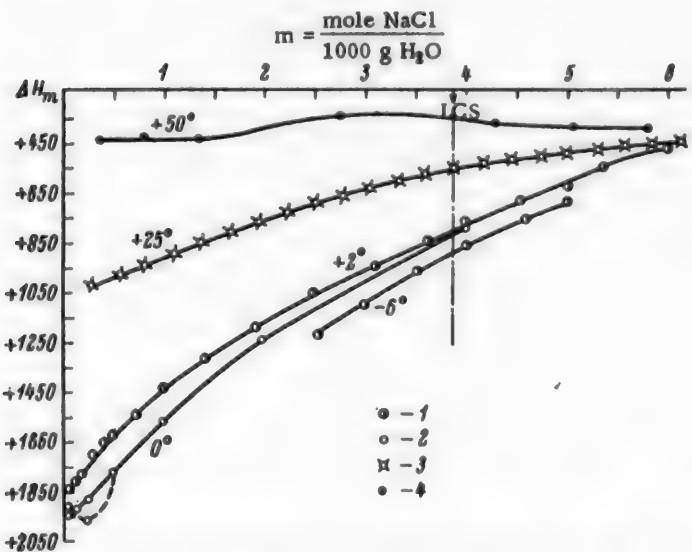
Fig. 2. Isotherms of integral heats of solution of NaCl in water at various temperatures: 1) our data; 2) data of Scholz and Lehtonen; 3) data of Wüst and Lange; 4) data of Voskresenskaya and Yankovskaya.
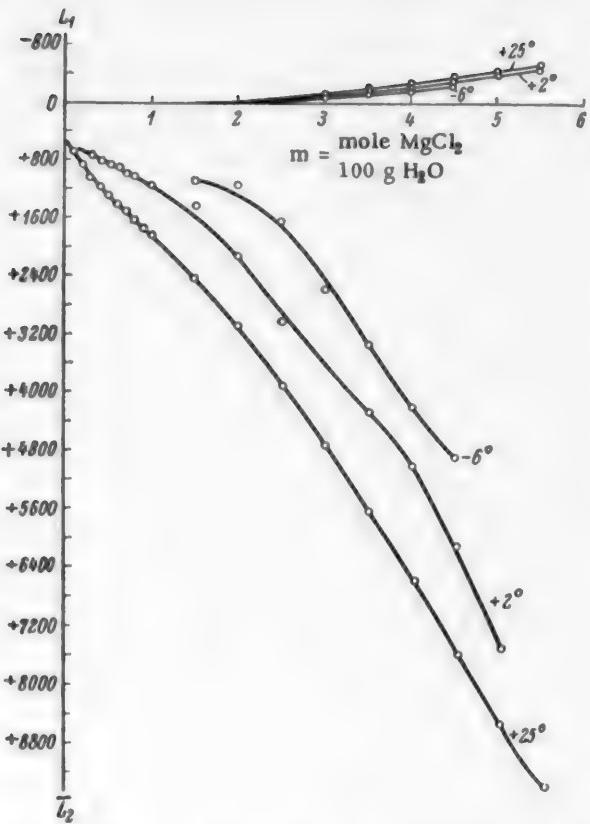
Fig. 3. Isotherms of the partial molal enthalpies of water and MgCl₂ at various temperatures.
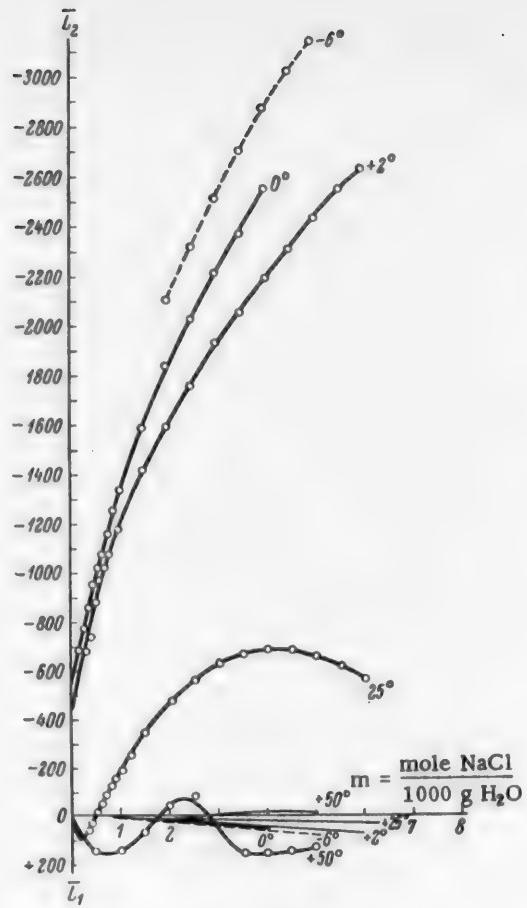
Fig. 4. Isotherms of partial molal enthalpies of water and NaCl at various temperatures.

or

$$\Delta H_{m2} = \frac{\Delta H_{m3} \frac{g_1 + g_2}{M} - \Delta H_{m1} \frac{g_1}{M} - \Delta Q_{expt.}}{\frac{g_2}{M}}$$

Here ΔH_{m_1}, ΔH_{m_2}, and ΔH_{m_3} are the integral heats of formation of solutions of concentration m_1, m_2, and m_3. The values of ΔH_{m_1} and ΔH_{m_3} were found from a graph of $\Delta H_m = f(m)$, and ΔH_{m_2} was calculated from the equation presented above; g_1 and g_2 are the weights of salt in solutions of concentration m_1 and m_2; Q_{expt} is the heat of dilution, in calories.

The intermediate data and detailed calculations were presented in [6].

On the basis of the experimental material we obtained, combined with literature data already available, we constructed curves of the dependence $\Delta H_m = f(m)$ (Figs. 1 and 2), and also calculated the temperature coefficients $(\Delta H_m/\Delta T)$ and the relative partial molal enthalpies over wide temperature and concentration ranges.

Tables 4 and 5, and Figs. 3 and 4, show the concentration dependencies we found for the partial molal enthalpies of water $(\overline{L}_1)$ and the corresponding salt $(\overline{L}_2)$ for several temperatures.

DISCUSSION OF RESULTS

On the example of the NH_4CL-H_2O system at 25°, for which the exothermal heat of solution increases with an increase in concentration (class II) [12, 13], K. P. Mishchenko and A. M. Ponomareva [14] observed that with an increase in temperature, the curves of $\Delta H_m = f(m)$ regularly changed their form right up to a change to the opposite slope, i.e., the exothermal heat began to decrease with an increase in concentration (class I) [12, 13]. A tendency for similar changes was also observed in our laboratory on the example of certain other systems ($CoCl_2-H_2O$; $MgSO_4 \cdot 7H_2O-H_2O$, etc.). Such a change in the isotherms of the integral heats of solution from class to class is apparently determined mainly by the relative effect of the disruption of the structure of the water and the dehydration of ions at elevated temperatures. Therefore, one of the problems of this work was to show that this phenomenon was general, on the basis of the characteristics of the temperature displacement of the $\Delta H_m = f(m)$ isotherms for all types of salts over a wide range of temperatures.

The isotherms of $\Delta H_m = f(m)$ we obtained for salts of both class I and II at +2 and −6°, combined with available high-temperature isotherms, made it possible for us to formulate the rules of the observed phenomena more definitely.

First of all, for all the systems studied, we observed the following rule: with an increase in temperature, curves, which were typical of class I at 25°, increased their slope in the direction of a fall in the exothermal heat. On the other hand, curves of class II decreased their slope in the direction of an increase in the exothermal heat. Thus, with an increase in temperature, all types of solution are characterized by the same tendency: a growth in the endothermal part, and a decrease in the exothermal part, of the effects forming the integral heat of solution. Figs. 1 and 2 illustrate this. In this connection, with a sufficient increase in temperature, curves of class II change into those of class I, and curves of class I become even more sharply expressed. Therefore, it was to be expected that curves of class I might acquire the form of class II curves, on the other hand, at sufficiently low temperatures.

Actually, when the temperature was reduced to +2 and then to −6°, the $\Delta H_m = f(m)$ isotherms we obtained for a typical representative of class I, $MgCl_2 \cdot 6H_2O$, in the concentration range up to the limit of complete solvation (LCS) [15] became closer to class II. It is true that we were unable to reach a temperature at which the $\Delta H_m = f(m)$ isotherm for $MgCl_2 \cdot 6H_2O-H_2O$ would be characterized by an increase in the exothermal heat with concentration, but, on the other hand, in this case, we were able to observe a zone of practically complete independence of ΔH_m of concentration in a region of not too concentrated solutions (Fig. 1).

The second interesting peculiarity of the picture we observed was a clear tendency for the $\Delta H_m = f(m)$ isotherms to draw together in the region of high concentrations, and for the $MgCl_2 \cdot 6H_2O-H_2O$ system, we even found that the isotherms for +2° and +25° merged.

The $\Delta H_m = f(m)$ isotherm at 50° on Fig. 2 ($NaCl-H_2O$ system) passed through a maximum, and belonged to class III in accordance with the classification [12, 13]. According to the data of Wüst and Lange [11], a small maximum is observed for this system close to saturation concentration on the 25° isotherm also, but at lower temperatures the $\Delta H_m = f(m)$ isotherms are typical of class II.

The change in the course of the $\Delta H_m = f(m)$ curves with temperature, and the possibility of their change from one class to another may be explained by the fact that with a change in temperature, the separate endo- and exo-effects, forming the integral heat of solution, change differently. Here it should be borne in mind that a change in the structure of the solvent may affect the course of the $\Delta H_m = f(m)$ curves only up to the limit of complete solvation, and to a temperature of 80°, while there still exist the structural forms of water I−II−III in the sense of the Bernal and Fowler model [16]. Consequently, the endothermal effect, connected with disruption of the pseudocrystalline structure of water, may appear only up to this temperature, and only up to the LCS. This leads to the fact that with an increase in temperature, the slope of the $\Delta H_m = f(m)$ curves for systems of class II become less steep, finally one of the isotherms is horizontal, and then, at higher temperatures, the isotherms change to class I.

It is known that the endo effect of energetic desolvation decreases with an increase in temperature since the force with which the water molecules are held in the solvated complexes is weakened. However, even without the "structural endo effect," this value will still dominate the exo effect of the approach of ions, and will also lead to a change into class I. The exo effect of ion approach is almost temperature independent, although the dielectric permeability decreases slightly with an increase in temperature, and this must facilitate the growth

of the exo effect. This growth is compensated for by the decrease due to thermal expansion of the solution and, in any case, cannot be an appreciable value up to the LCS. At high concentration beyond the LCS, the exo effect of the approach of ions may have a comparatively high value due to the openness of the solvation sheath at elevated temperatures. If, in addition, beyond the LCS there appears coordination desolvation with disproportionation of water to the advantage of a more hydrophilic ion with an additional exo effect, then it may happen that the total exo effect will dominate all the other effects. In this case, the end of the $\Delta H_m = f(m)$ curve changes into class II and if the first part of the isotherm, up to the LCS, is of class I, then we will have the type of curves of class IV with an exothermal heat minimum.

The change of $\Delta H_m = f(m)$ curves from class I to II with a decrease in temperature is explained by the same considerations, namely, that at low temperatures the movement of the particles is small and, therefore, right up to the LCS, energetic desolvation decreases slightly. However, with a decrease in temperature, there is a considerable increase in the endo effect, connected with disruption of the pseudocrystalline structure of water, and this makes the total endo effect in this concentration region strongly endothermal.

At some temperature, the endo effect will be compensated by the exo effect of ion approach, and we obtain a horizontal section of the line (see Fig. 1). Further growth of the endothermal heat leads to a curve slope of the type of class II (if a liquid phase exists at these temperatures), or gives a curve of class III with an exothermal heat minimum. Thus, the chance observation of a horizontal path for one of the sections of the $\Delta H_m = f(m)$ isotherms at some temperature cannot be considered as an indication of some specific structure for the solutions at this temperature, but is the result of mutual compensation of separate effects with opposite signs, which form the integral heat of solution.

The whole of the experimental material confirms our views on the structure of solutions, and gives us grounds for stating that separate sections of $\Delta H_m = f(m)$ isotherms may, in principle, be horizontal at definite temperatures for aqueous solutions of any salts. Here it is not at all obligatory that the whole isotherm should be horizontal for a change from class to class. The nature of the solutions in various concentration regions is so different that the mutual compensation of the exothermal and endothermal parts of ΔH_m may occur in various concentration zones at various temperatures. In our opinion, exactly this circumstance may lead to the appearance of isotherms of classes III or IV at certain temperatures.

It is possible to establish some qualitative rule relating the temperature region in which the $\Delta H_m = f(m)$ isotherms change from class I to II, or the reverse, on the one hand, and the nature of the electrolyte ions, on the other. The greater the solvation energy of the ions, comprising the given electrolyte, the lower must lie the temperature of this transition zone; on the other hand, the more weakly the ions are solvated, the higher will be the temperature of this region. This rule is quite understandable in the light of the ideas developed above, and is confirmed by the experimental material we have accumulated.

In the case of solutions of the weakly solvated NH_4Cl ($\Delta H_h^{NH_4^+} = -78$ kcal/g·ion and $\Delta H_h^{Cl^-} = -84$ kcal per g·ion) the transition zone of the isotherm occurs in the region of 35-37°, and, in the case of solutions of the strongly solvated $MgCl_2$ ($\Delta H_h^{Mg^{++}} = -467$ kcal/g·ion) this zone is displaced to the region of $-6°$. It can be predicted with certainty that for $CaCl_2$ ($\Delta H_h^{Ca^{++}} = -386$ kcal/g·ion) this temperature lies above $-6°$, and for $BaCl_2$ ($\Delta H_h^{Ba^{++}} = -320$ kcal/g·ion) it is even higher. On the other hand, in the case of solutions of BaF_2, which have not been studied, this zone must be displaced considerably below $-6°$. The phenomena examined above compel one to admit that the classification of electrolytes according to the character of the slopes of the $\Delta H_m = f(m)$ isotherms, proposed in their time by Mishchenko and Pronina [13], and developed by Voskresenskaya and Yankovskaya [10] are only applicable in the temperature range around room temperature.

The tendency of the $\Delta H_m = f(m)$ isotherms to approach in the concentration region beyond the LCS, which we found, remains to be explained.

Although the structure of the solutions is considerably more complex in this zone, and it is more difficult to explain the series of rules observed here, nonetheless, we have a basis for stating that, beyond the LCS, the qualitative pictures of the solution structure at all temperatures and for all types of salts are somewhat similar to each other. Here, the main role is played by the exo effects of ion interaction, which depend very little on temperature. This leads to the approach, and even practical mergence, of the $\Delta H_m = f(m)$ curves, as may be seen on our diagrams.

Naturally, the values of the partial enthalpies and the temperature coefficients calculated from these data confirm these conclusions on the transition of the systems studied from one thermochemical class to another, and the character of the changes observed. For the $MgCl_2 \cdot 6H_2O - H_2O$ system, the predicted increasingly steep fall in the $\bar{L}_2$ curves, with an increase in temperature [12], was confirmed (Fig. 3). In the case of the $NaCl - H_2O$ system, the experimental isotherm of the integral heats of solution at 50° [10], about which we were doubtful, stands out even more sharply as unreliable (Fig. 4).

SUMMARY

1. The integral heats of solution of NaCl, $MgCl_2 \cdot 6H_2O$ and $MgCl_2$ at temperatures of +2 and —6° were measured over a wide concentration range. The corresponding partial molal enthalpies of water and the electrolyte under the same conditions were calculated.

2. An examination of the concentration and temperature dependencies of these properties obtained, in conjunction with literature data, made it possible to arrive at certain conclusions on the structure of concentrated solutions of electrolytes and its change with temperature.

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VAPOR PRESSURE OF SYSTEMS FORMED BY STANNIC CHLORIDE WITH ESTERS

M. Usanovich and A. Dembitskii

Institute of Chemical Sciences, Academy of Sciences, KazSSR

Original article submitted May 7, 1958

In an investigation of the vapor pressure of the $SnCl_4-C_6H_5OH$ system, a positive deviation from Raoult's law was observed with chemical interaction present in the system [1]. At first sight, this remarkable fact was explained by a decrease in the number of particles from the formation of the compound $SnCl_4 \cdot 4C_6H_5OH$.

Since, in systems formed by stannic chloride with esters, interaction between the components leads to the formation of the compounds $SnCl_4 \cdot 2A$ [2-8], we decided to study the vapor pressures of these systems, expecting to find positive deviations from Raoult's law and also additional confirmation of the composition and structure of complexes of stannic chloride with esters [8-11].

An article by Yu. N. Vol'nov, which appeared recently, was devoted to a study of the vapor pressure of three of these systems [12]. We consider that the appearance of Vol'nov's work does not preclude the publication of our results, since we measured not only the total, but also the partial vapor pressure; in addition, our data do not agree completely with those of Vol'nov.

EXPERIMENTAL

The esters we synthesized, and the stannic chloride, were purified by fractional distillation. The best fractions were distilled and sealed in ampules on a special apparatus [13]. The stannic chloride was distilled over P_2O_5. Our preparations were characterized by the constants presented in Table 1.

TABLE 1

Substance	Boiling point (pressure,mm)	n^{20} according to lit. [15]	n^{20} our data
Stannic chloride	110.3° (692)	—	—
Ethyl acetate	74.3 (692)	1.3728	1.3729
n-Butyl acetate	122.5 (692)	1.3951	1.3950
Isoamyl acetate	137.0 (697)	1.4014	1.4013
n-Butyl propionate	141.0 (691)	—	1.4012
Ethyl propionate	96.2 (693)	1.3839	1.3839
n-Butyl formate	103.2 (693)	1.3891	1.3893

The vapor pressure was measured in the apparatus illustrated in Fig. 1. The liquid was stirred with a glass stirrer 1, the upper part of which contained an iron ring 2, sealed into the glass. The stirrer was operated by an electromagnet 3, powered by a multivibrator [14]. The ebullioscope was fitted with an electrical heater 4, sealed in a glass tube, and an outer jacket 5, within which was circulated water from an ultrathermostat.

The vapor pressure was measured over the temperature range from 15 to 97°. From the data obtained, we constructed $\lg P - 1/T$ diagrams, the appropriate sections of which gave the vapor pressure isotherms. In determining the partial vapor pressure, the condensate was analyzed for tin by a gravimetric method. The heat of evaporation was calculated from the Clapeyron—Clausius equation. The results of measuring the temperature dependence of the total and partial vapor pressures of the systems

Fig. 1. Apparatus for measuring total and partial vapor pressure. Explanation in text.

$SnCl_4\cdots HCOOC_4H_9,$
$SnCl_4-CH_3COOC_2H_5,$
$SnCl_4-C_2H_5COOC_2H_5,$
$SnCl_4-CH_3COOC_4H_9,$
$SnCl_4-C_2H_5COOC_4H_9$

and $SnCl_4-CH_3COOC_5H_{11}$ are given in Tables 2-13, respectively.

Figures 2 and 3 show the total and partial vapor pressure isotherms, and also curves showing the dependence of the heat of evaporation on the vapor composition.

As is seen from data in the tables and figures, in all systems the same picture was observed, in general. Along their whole course, the isotherms of the partial vapor pressure of the esters lie below the additive lines, touching the latter at 100% ester. With a considerable excess of stannic chloride, the partial vapor pressures of the esters fall practically to zero (the curves touch the abscissa). In all systems, the curves of the partial vapor pressure of stannic chloride are characterized by positive deviations from additive lines in the concentration region from 50-70 to 100 mole% of stannic chloride, and by negative deviations at lower stannic chloride contents. These curves do not touch the additive line close to 100% of stannic chloride, and have a horizontal tangent on approaching 0% of stannic chloride. Thus, at up to approximately 20 mole% of stannic chloride, the vapor contains practically only ester, and from approximately 60 mole% of $SnCl_4$, stannic chloride. This is confirmed independently by the heats of evaporation we calculated for the corresponding concentration regions, which coincide with the corresponding heats of evaporation of the components.

All this indicates extensive chemical interaction in the system. The positive deviation of the partial vapor pressures of stannic chloride from the additive line is caused by an increase in the mole fraction of the stannic chloride, occurring as a result of interaction with the esters. This increase in the mole fraction of the stannic chloride must occur with the condition that the number of particles arising as a result of the interaction is less than the number of ester molecules undergoing the reaction. Therefore, the formation of the compound $SnCl_4 \cdot 2RCOOR'$ must produce a positive deviation, since a particle of the complex contains two RCOOR' molecules. However, had $SnCl_4 \cdot 2RCOOR'$ dissociated into two ions, then the number of particles formed would not have differed from the number of RCOOR' molecules entering the complex, and there would not have been a positive deviation. With the formation of the compound $SnCl_4 \cdot 3RCOOR'$, which dissociates into two ions, a positive deviation must have been observed.

Thus, the particular course of the partial vapor pressure of stannic chloride excludes the possibility that the sole complex compound in each of the systems investigated is $SnCl_4 \cdot 2RCOOR'$, which is electrolytically dissociated. This result is in complete agreement with previous experimental data and theoretical ideas [8-11].

The total vapor pressure of all the systems investigated is characterized by considerable negative deviations from additivity and the appearance of azeotropic mixtures, containing 35-40 mole% of stannic chloride. This indicates the formation of nonvolatile compounds of stannic chloride with esters.

The curves representing the composition dependence of the heats of evaporation pass through a maximum in the region of 25-35 mole% of stannic chloride and, in our opinion, this reflects the formation of the compounds $SnCl_4 \cdot 2RCOOR'$ and $SnCl_4 \cdot 3RCOOR'$.
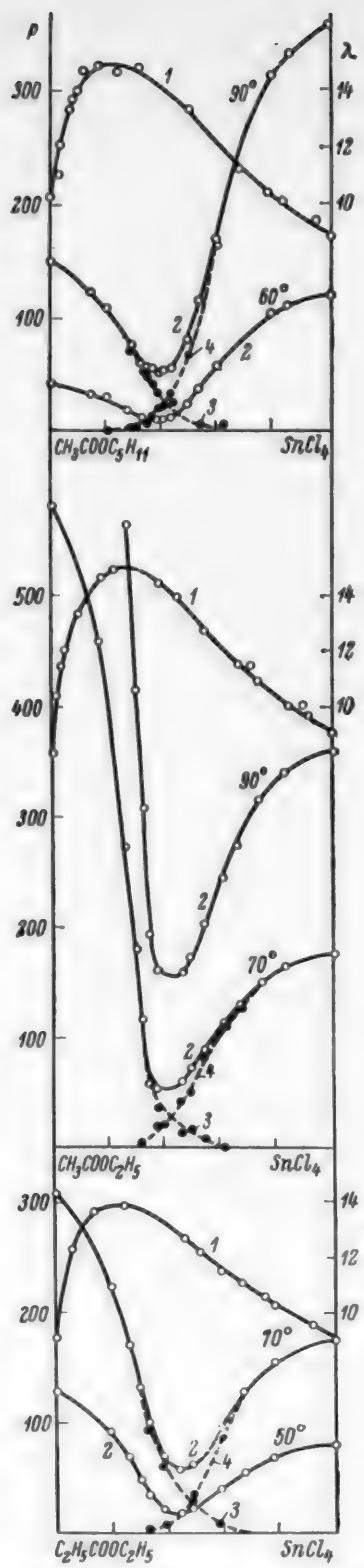
Fig. 2. Vapor pressure and heats of evaporation of the systems $SnCl_4$–$C_2H_5COOC_2H_5$, $SnCl_4$–$CH_3COOC_2H_5$, and $SnCl_4$–$CH_3COOC_5H_{11}$: 1) heat of evaporation; 2) total vapor pressure; 3) partial pressure of $C_2H_5COOC_4H_9$; 4) partial pressure of $SnCl_4$.
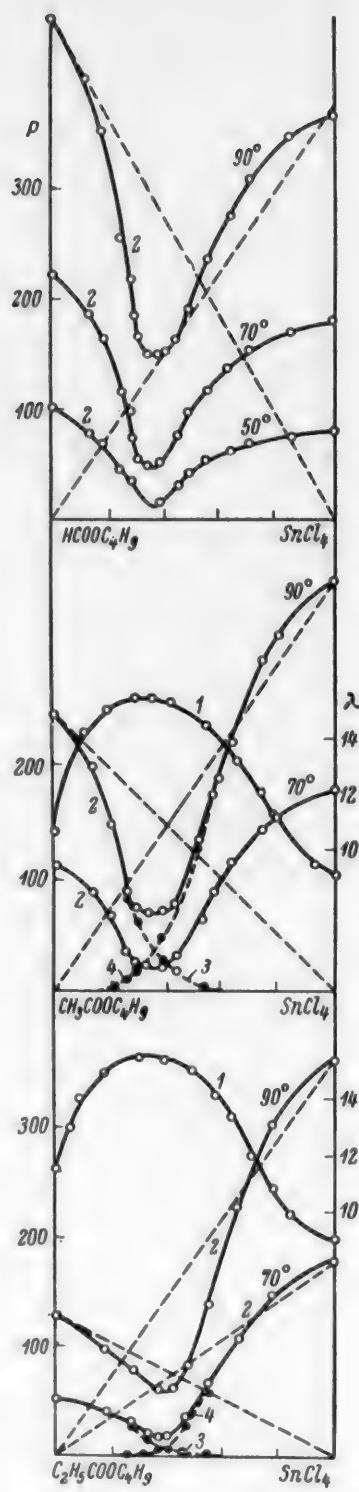
Fig. 3. Vapor pressure and heats of evaporation of the systems $SnCl_4$–$C_2H_5COOC_4H_9$, $SnCl_4$–$CH_3COOC_4H_9$, and $SnCl_4$–$HCOOC_4H_9$: 1) heat of evaporation; 2) total vapor pressure; 3) partial pressure of $C_2H_5COOC_4H_9$; 4) partial pressure of $SnCl_4$.

TABLE 2

$SnCl_4$ – iso-$CH_3COOC_5H_{11}$

SnCl₄ content (in mole %)	Boiling point (upper figures) Vapor pressure (mm Hg) lower figures										
100.0	9.6° 10.2	19.2° 18.1	29.5° 30.6	39.8° 50.5	50.9° 81.0	60.0° 122	70.0° 180	80.0° 259	90.1° 362	97.0° 458	
85.0	18.5° 17.0	25.6° 23.5	31.6° 31.5	37.5° 41.5	42.3° 51.0	47.1° 65.0	53.1° 82.0	64.2° 131	73.0° 181	81.0° 243	87.3° 306
79.0	25.7° 22.0	32.0° 30.0	40.2° 44.0	46.5° 58.0	52.8° 78.0	60.7° 107	67.5° 138	75.8° 187	84.2° 257	90.0° 310	96.0° 383
60.0	32.0° 16.0	37.5° 21.0	45.2° 30.0	53.2° 42.0	61.0° 57.5	66.9° 73.0	78.0 111	87.9° 159	93.7° 193		
53.0	37.1° 12.5	46.3° 19.5	49.2° 22.0	59.3° 34.5	65.5° 45.0	73.7° 63.0	77.9° 74.5	81.0° 83.0	83.8° 90.5	91.2° 121	95.7° 144
49.0	44.8° 11.0	48.7° 13.0	52.5° 16.0	56.2° 19.0	65.0° 28.0	72.6° 39.0	77.9° 48.0	81.6° 57.0	86.8° 70.0	90.2° 82.0	95.7° 98.5
43.3	62.7° 12.0	66.7° 15.5	69.2° 18.0	73.1° 22.0	76.2° 26.5	79.9° 32.0	84.2° 40.5	87.8° 49.5	91.0° 58.0	95.6° 74.5	
38.0	62.4° 9.5	65.2° 11.5	69.8° 13.0	72.2° 18.0	75.2° 22.0	77.2° 25.0	82.1° 33.5	87.5° 45.0	91.2° 55.5	96.2° 72.0	
36.0	58.4° 8.5	62.9° 10.5	65.5° 12.5	69.6° 16.5	74.5° 22.5	80.0° 32.0	84.6° 42.0	90.3° 57.5	95.2° 74.0		
33.8	61.1° 10.0	64.2° 12.0	68.6° 16.0	73.8° 22.0	80.3° 33.0	83.7° 40.0	89.4° 55.0	94.9° 75.0			
33.0	53.8° 7.0	57.1° 9.0	61.9° 12.0	67.2° 17.0	71.9° 22.5	78.3° 32.0	82.2° 40.0	86.9° 53.5	90.2° 62.0	96.0° 82.0	
28.0	57.9° 14.5	65.8° 22.5	74.9° 36.0	79.9° 47.0	86.7° 65.0	91.3° 80.5	94.1° 93.5				
20.0	51.4° 24.0	61.5° 30.0	66.3° 39.0	75.9° 61.0	82.1° 81.0	88.8° 105	94.2° 134				
14.0	55.3° 26.3	60.0° 32.0	66.5° 45.0	73.5° 61.0	80.0° 81.0	85.2° 102	90.2° 123	94.2° 144			
0.0	40.6° 15.0	47.5° 22.0	58.0° 37.0	64.0° 49.0	71.8° 70.0	77.5° 89.5	83.4° 114	88.0° 142	94.5° 180		

TABLE 3

$SnCl_4$ – iso-$CH_3COOC_5H_{11}$

SnCl₄ content of mixture (in mole %)	Vapor pressure		SnCl₄ content of mixture (in mole %)	Partial vapor pressures		Heat of evaporation (in kcal/mole)
	60°	90°		SnCl₄	CH₃COOC₅H₁₁	
100.0	118	363	100	363		8.9
85.0	110	334	—	—	—	8.9
79.0	103	313	—	—	—	8.9
60.0	56.0	170	98.6	167.5	2.5	8.9
53.0	36.0	116	95.4	110.7	5.3	9.4
49.0	22.0	80.0	83.5	67.0	13.0	10.1
43.0	10.0	55.0	56.0	32.0	23.0	13.5
40.0	9.0	53.0	40.5	21.5	31.5	14.1
38.0	8.2	52.0	36.3	19.0	33.0	14.7

(more)

TABLE 3 (continued)

SnCl₄ content of mixture (in mole %)	Vapor pressure		SnCl₄ content of condensate (in mole %)	Partial vapor pressures		Heat of evaporation (in kcal/mole)
	60°	90°		SnCl₄	CH₃COOC₅H₁₁	
36.0	8.7	55.5	24.0	13.3	42.2	14.8
34.0	9.5	56.0	11.5	6.5	49.5	14.8
33.8	9.8	57.5	8.0	4.5	53.0	14.7
33.3	10.5	60.0	8.4	5.0	55.0	13.7
28.0	16.5	76.0	1.5	1.0	75.0	12.3
20.0	29.5	109	0.7	0.76	108	10.8
14.0	32.0	122	—	—	—	10.6
0.0	41.0	149	0	—	—	10.5

TABLE 4

$SnCl_4 - C_2H_5COOC_2H_5$

Boiling point (upper figures)
Vapor pressure (mm Hg) (lower figures)

SnCl₄ content (mole %)												
100.0	9.6°	19.2°	29.5°	39.8°	50.9°	60.0°	70.0°	80.0°	90.1°	97.0°		
	10.2	18.1	30.6	50.5	81.0	122	180	259	362	458		
78.0	23.3°	26.6°	32.2°	36.6°	45.2°	50.2°	57.4°	64.0°	68.3°	75.0°	83.3°	91.5°
	19.5	22.7	28.7	36.9	55.0	69.1	92.7	120	140	180	243	322
67.0	29.2°	33.5°	41.2°	50.6°	59.4°	67.4°	75.3°	84.4°	92.5°			
	21.0	26.0	37.3	55.5	81.9	111	151	212	283			
59.0	37.2°	41.5°	48.7°	56.0°	65.9°	71.4°	78.2°	85.3°	92.0°			
	21.0	27.0	37.0	50.4	76.6	96.6	127	165	211			
48.4	41.3°	44.5°	47.5°	52.4°	59.1°	65.4°	73.4°	80.0°	89.2°	96.2°		
	13.0	15.2	18.0	24.0	36.5	46.3	68.5	94.0	140	192		
43.7	48.2°	51.1°	58.1°	64.5°	69.5°	74.1°	78.6°	83.0°	89.0°	92.4°		
	14.5	17.5	26.5	38.5	52.0	66.0	85.0	107	148	175		
38.1	48.4°	52.9°	56.4°	63.4°	68.4°	72.7°	76.5°	82.1°	85.9°	90.5°		
	17.7	23.3	29.3	44.6	60.5	75.6	94.5	128	160	199		
33.4	48.2°	50.8°	56.0°	60.0°	63.5°	67.3°	74.4°	80.2°	83.5°	87.8°	94.4°	
	29.3	34.0	45.0	58.0	69.3	85.0	121	157	186	227	298	
30.0	40.0°	46.2°	50.4°	57.3°	61.8°	68.1°	76.0°	84.4°	91.2°			
	27.8	39.0	49.0	68.5	85.5	116	166	239	317			
26.0	24.0°	32.4°	43.1°	50.1°	58.7°	66.2°	73.0°	81.0°	90.5°			
	19.0	29.3	48.3	69.8	102	140	185	253	362			
19.0	20.5°	30.0°	38.8°	49.0°	57.7°	66.8°	76.5°	84.9°	90.6°			
	19.8	34.5	54.0	88.0	127	186	269	366	447			
0.0	23.0°	26.2°	29.3°	35.0°	41.6°	47.1°	53.8°	59.2°	65.0°	71.5°	77.8°	85.0°
	36.0	41.7	49.7	65.4	87.4	112	149	188	236	305	384	493

TABLE 5

$SnCl_4 - C_2H_5COOC_2H_5$

SnCl₄ content of mixture (in mole %)	Vapor pressure		SnCl₄ content of condensate (in mole %)	Partial vapor pressures		Heat of evaporation (in kcal/mole)
	50°	70°		SnCl₄	C₂H₅COOC₂H₅	
100.0	78.0	178	100.0	178	—	8.9
78.0	66.0	155	—	—	—	8.7
67.0	54.0	128	—	—	—	9.4

(more)

SnCl₄ content of mixture (in mole %)	Vapor pressure		SnCl₄ content of condensate (in mole %)	Partial vapor pressures		Heat of evaporation (in kcal/mole)
	50°	70°		SnCl₄	C₂H₅COOC₂H₅	
59.0	39.5	95.0	92.0	87.5	7.5	9.6
48.5	21.0	61.0	46.3	128	33.0	12.8
44.0	16.0	56.0	—	—	—	13.7
38.0	20.0	69.0	13.7	8.5	60.5	13.7
33.3	33.0	100	2.4	2.5	97.5	12.3
30.0	47.5	132	—	—	—	11.3
26.0	68.5	171	—	—	—	9.8
19.5	91.0	225	—	—	—	9.5
0.0	128	306	0	—	306	9.2

T A B L E 6

$SnCl_4 - CH_3COOC_4H_9$

SnCl₄ content (in mole %)	Boiling point (upper figures) Vapor pressure (mm Hg) (lower figures)										
100.0	9.6°	19.2°	29.5°	39.8°	50.9°	60.0°	70.0°	80.0°	90.1°	97.0°	
	10.2	18.1	30.6	50.5	81.0	122	180	259	362	458	
80.0	22.0°	30.8°	37.7°	44.2°	52.5°	61.2°	68.0°	76.0°	82.1°	88.2°	91.6°
	17.5	28.0	39.0	53.0	78.5	110	143	193	245	312	336
74.0	25.0°	30.7°	39.1°	49.2°	57.8°	67.8°	77.6°	86.7°	96.5°		
	18.5	25.0	37.5	60.5	87.5	131	189	260	369		
63.0	29.4°	39.3°	46.4°	53.0°	62.3°	70.2°	75.8°	84.7°	90.2°	94.5°	
	19.5	31.5	42.5	58.0	83.0	111	138	191	234	272	
57.0	33.8°	42.0°	49.3°	59.1°	67.5°	76.9°	86.4°	95.8°			
	18.0	26.0	37.0	55.5	76.5	109	152	212			
52.6	45.7°	50.2°	55.2°	58.7°	63.5°	68.3°	73.5°	78.2°	83.5°	89.4°	93.4°
	21.0	26.5	33.0	38.5	46.5	56.5	69.0	82.5	99.0	124	146
43.6	60.0°	65.1°	71.8°	76.2°	81.6°	86.3°	90.0°	93.0°	95.6°		
	14.5	19.5	27.5	35.5	47.0	59.0	71.0	83.5	95.0		
38.6	65.2°	69.4°	74.0°	77.6°	80.9°	84.3°	89.4°	92.0°	96.4°		
	15.0	19.5	26.5	33.0	40.5	48.0	64.0	75.0	94.0		
33.2	69.5°	72.0°	76.1°	80.0°	83.2°	88.0°	92.0°	94.5°			
	17.5	20.5	27.5	35.0	43.0	58.5	75.0	88.0			
29.6	59.3°	64.5°	68.1°	72.9°	77.5°	81.8°	85.4°	90.0°	92.4°		
	10.0	14.0	18.0	25.0	33.0	43.5	53.5	69.0	79.5		
26.0	57.2°	61.0°	65.7°	71.8°	77.8°	86.8°	89.1°	95.7°			
	14.5	18.0	24.0	33.0	44.5	72.0	82.0	115			
20.5	38.5°	45.7°	52.3°	56.0°	58.7°	63.5°	69.0°	73.3°	80.2°	87.6°	96.3°
	14.0	20.0	28.0	32.5	38.5	46.5	62.0	77.0	97.5	132	196
14.3	31.5°	36.6°	44.0°	50.6°	58.1°	65.4°	73.3°	78.3°	85.7°	90.3°	95.8°
	12.0	17.0	25.5	35.0	51.0	71.0	98.0	122	167	198	240
0.0	24.5°	33.0°	43.0°	51.2°	57.7°	65.2°	71.1°	77.5°	83.7°	88.8°	94.1°
	11.7	19.0	31.0	46.5	64.0	90.0	115	151	192	233	316

TABLE 7

SnCl₄ – CH₃COOC₄H₉

$SnCl_4 - CH_3COOC_4H_9$

SnCl₄ content of mixture (mole %)	Vapor pressure			SnCl₄ content of condensate (in mole %)	Partial vapor pressure		Heat of evaporation (in kcal/mole)
	50°	70°	90°		SnCl₄	CH₃COOC₄H₉	
100.0	78.0	178	363	100.0	363	—	8.9
80.0	68.2	154	316	—	—	—	8.9
74.0	61.7	140	292	—	—	—	9.0
63.0	48.8	112	217	—	—	—	9.1
57.0	37.4	84.7	174	99.8	174	—	9.0
52.6	26.0	60.7	129	97.5	124	5	9.4
43.6	8.0	25.5	72.0	—	—	—	12.9
38.6	5.4	20.6	67.3	67.0	44.0	23.0	14.7
33.2	4.0	18.0	66.0	—	—	—	15.5
29.6	5.3	20.6	69.3	19.0	13.3	56.0	14.9
26.0	9.5	30.0	85.0	7.0	6.0	79.0	12.7
20.5	25.0	64.0	147	0.76	1	146	10.4
14.3	34.3	86.0	198	—	—	198	10.3
0.0	44.5	111	250	0	0	250	10.2

TABLE 8

SnCl₄ – C₂H₅COOC₄H₉

$SnCl_4 - C_2H_5COOC_4H_9$

SnCl₄ content (in mole %)	Boiling point (upper figures) / Vapor pressure (mm Hg) (lower figures)										
100.0	9.6°	19.2°	29.5°	39.8°	50.9°	60.0°	70.0°	80.0°	90.1°	97.0°	
	10.2	18.1	30.6	50.5	81.0	122	180	259	362	458	
78.1	25.2°	32.7°	39.6°	49.2°	57.0°	66.0°	75.4°	83.4°	90.0°		
	21.0	31.0	42.5	64.5	89.5	128	185	243	304		
66.0	32.0°	36.9°	44.2°	49.5°	57.2°	63.9°	69.8°	75.4°	81.3°	87.8°	93.8°
	22.0	28.0	38.0	48.0	66.0	86.0	109	132	166	208	255
55.6	34.4°	40.4°	47.8°	55.8°	64.7°	74.2°	81.2°	88.3°	95.2°		
	14.5	19.5	27.0	38.0	54.0	78.0	100	132	167		
47.3	57.0°	59.5°	60.7°	64.2°	67.3°	70.0°	76.1°	80.8°	87.1°	95.5°	
	17.0	19.0	20.0	24.0	28.5	32.0	42.0	52.5	68.5	103	
41.3	58.9°	63.4°	66.6°	70.0°	74.1°	80.1°	85.0°	90.3°	93.9°		
	9.0	12.0	15.0	18.5	24.0	35.0	45.5	60.5	78.5		
37.4	55.3°	61.4°	68.6°	70.4°	73.9°	79.1°	84.6°	90.5°	95.2°		
	6.5	10.0	16.0	18.0	22.0	32.0	43.0	60.0	80.0		
33.1	47.3°	52.7°	59.0°	61.8°	68.1°	70.0°	73.8°	77.4°	83.3°	89.4°	95.6°
	5.5	7.5	11.5	13.5	19.5	22.0	27.0	33.5	45.5	63.0	86.0
28.2	58.8°	63.5°	68.2°	70.2°	74.6°	79.6°	85.0°	95.0°			
	15.5	20.5	26.0	29.0	37.0	48.0	62.0	96.0			
18.7	49.5°	55.5°	60.7°	65.3°	69.9°	77.3°	84.0°	90.6°	95.2°		
	15.5	20.5	27.5	33.5	40.5	56.0	76.0	100	120		
0.0	32.4°	36.3°	43.9°	50.5°	57.5°	64.3°	70.1°	76.8°	81.3°	86.7°	92.9°
	6.5	8.5	13.0	19.0	28.0	39.0	52.0	70.0	88.0	112	148

TABLE 9

SnCl$_4$–C$_2$H$_5$COOC$_4$H$_9$

SnCl$_4$ content of mixture (in mole %)	Vapor pressure			SnCl$_4$ content of condensate (in mole %)	Partial vapor pressures		Heat of evaporation (in kcal/mole
	50°	70°	90°		SnCl$_4$	C$_2$H$_5$COOC$_4$H$_9$	
100.0	78.0	178	363	100.0	178	—	8.9
78.0	67.0	149	304	—	—	—	8.9
66.0	49.5	108	224	—	—	—	8.9
55.0	29.7	67.5	140	99.7	67.0	0.5	9.0
47.0	11.5	34.5	79.5	81.0	28.0	6.5	11.3
41.0	5.0	18.5	61.0	49.7	9.2	9.3	14.7
37.0	4.4	17.5	60.0	32.4	5.7	11.8	15.2
33.0	6.5	22.0	65.0	11.0	2.5	19.5	13.4
28.0	9.5	29.0	79.0	1.3	0.3	28.7	12.2
18.6	15.9	41.5	97.0	—	—	—	11.3
0.0	18.5	52.0	123	0	—	52.0	11.4

TABLE 10

SnCl$_4$–CH$_3$COOC$_2$H$_5$

SnCl$_4$ content (in mole %)	Boiling point (upper figures) Vapor pressure (mm Hg) (lower figures)									
100.0	9.6°	19.2°	29.5°	39.8°	50.9°	60.0°	70.0°	80.0°	90.1°	97.0°
	10.2	18.1	30.6	50.5	81.0	122	180	259	362	458
83.0	30.6°	38.0°	47.4°	54.5°	59.2°	65.0°	71.8°	80.4°	86.8°	94.5°
	29.5	42.5	65.0	88.0	108	136	179	243	306	394
74.0	33.9°	41.8°	45.9°	50.0°	55.4°	62.6°	70.0°	81.5°	90.0°	94.6°
	32.0	45.0	55.0	66.5	82.5	112	151	238	322	373
66.0	42.2°	50.0°	57.9°	62.0°	68.0°	78.0°	82.7°	87.0°	92.0°	96.2°
	40.5	57.5	78.5	93.0	119	175	210	242	288	329
61.0	28.9°	35.0°	40.0°	45.0°	50.0°	55.8°	60.0°	65.0°	70.0°	
	16.7	22.2	29.2	39.0	48.0	61.0	76.0	92.0	110	
54.0	47.6°	50.0°	57.0°	63.7°	70.0°	75.4°	82.8°	90.0°	95.0°	
	34.3	36.3	50.0	68.0	87.0	112	150	209	251	
49.0	48.9°	52.0°	57.8°	61.0°	65.8°	70.1°	75.0°	80.1°	90.2°	96.0°
	26.0	29.5	37.5	48.5	59.5	72.5	89.5	112	178	228
46.0	46.2°	50.3°	63.2°	73.3°	81.6°	84.5°	90.0°	94.3°		
	18.5	23.0	43.5	74.5	111	127	162	199		
37.0	51.4°	57.0°	60.3°	64.2°	70.1°	77.6°	82.0°	85.5°	90.2°	94.6°
	18.0	25.5	31.5	39.0	57.0	84.0	107	129	165	206
34.0	59.0°	67.0°	72.1°	76.5°	81.5°	84.0°	88.0°	90.0°	92.0°	95.4°
	28.5	48.5	68.5	88.5	121	138	172	196	217	264
30.0	37.5°	46.8°	50.6°	56.0°	62.0°	71.0°	76.9°	83.6°	87.0°	93.6°
	37.0	58.0	71.5	88.0	124	187	238	316	362	487
26.6	27.5°	34.5°	40.6°	51.2°	54.6°	62.0°	70.3°	77.9°	84.2°	88.0°
	37.0	59.0	78.0	127	149	195	266	367	463	532
16.6	19.0°	25.1°	30.4°	35.3°	40.8°	46.6°	56.6°	66.7°	70.1°	75.6°
	62.0	72.6	94.0	117	148	192	277	402	456	553
0.0	20.0°	30.0°	37.8°	50.0°	60.0°	70.0°				
	72.8	117	186	282	515	592				

TABLE 11

SnCl$_4$ – CH$_3$COOC$_2$H$_5$

SnCl$_4$ content of mixture (in mole %)	Vapor pressure			SnCl$_4$ content of condensate (in mole %)	Partial vapor pressure		Heat of evaporation (in kcal/mole)
	50°	70°	90°		SnCl$_4$	CH$_3$COOC$_2$H$_5$	
100.0	78.0	178	363	100.0	178	—	8.9
83.0	72.3	164	340	—	—	—	9.1
74.0	65.0	151	315	—	—	—	9.2
66.0	56.5	131	273	99.9	131	0	9.3
61.0	47.3	114	245	92.5	113	1.0	9.7
54.0	36.0	89.5	203	90.5	81.0	8.5	10.1
49.3	26.5	72.0	173	72.0	52.0	20.0	10.9
46.0	22.5	60.0	160	71.0	43.5	16.5	11.5
37.0	16.5	55.0	161	32.5	19.0	36.0	14.3
34.0	15.2	58.6	195	—	—	—	14.8
31.6	39.4	118	309	4.5	5.5	112	12.0
30.0	69.7	181	415	1.1	2.0	179	10.5
26.6	120	273	565	—	—	—	8.5
16.6	215	457	891	—	—	—	8.4
0.0	273	581		0	0	581	8.4

TABLE 12

SnCl$_4$ – HCOOC$_4$H$_9$

SnCl$_4$ content (in mole %)	Boiling point (upper figures) Vapor pressure (mm Hg) (lower figures)									
100.0	9.6°	19.2°	29.5°	39.8°	50.9°	60.0°	70.0°	80.1°	90.0°	97.0°
	10.2	18.1	30.6	50.6	81.0	122	180	259	362	458
86.2	19.7°	27.7°	36.2°	45.5°	54.6°	61.4°	68.5°	76.1°	85.4°	93.2°
	17.6	26.6	41.1	63.0	91.0	123	163	214	298	378 •
71.0	23.6°	33.5°	43.2°	51.6°	60.6°	68.7°	74.5°	80.8°	87.3°	94.2°
	20.5	32.5	49.8	72.0	104	144	174	217	275	351
64.3	18.0°	28.5°	37.0°	45.4°	54.7°	62.3°	69.4°	75.8°	83.2°	89.3°
	14.3	24.3	36.3	51.8	75.8	102	132	164	214	268
56.0	26.8°	35.9°	42.1°	52.7°	59.6°	65.8°	73.9°	82.9°	88.2°	94.3°
	19.3	29.3	39.3	59.0	79.0	99.0	133	181	220	272
49.5	31.4°	39.6°	49.4°	57.6°	64.5°	73.8°	79.1°	85.3°	98.2°	
	19.5	29.5	43.5	59.0	77.0	107	134	169	258	
45.0	46.8°	55.3°	65.7°	73.3°	81.9°	88.0°	94.4°			
	27.2	39.0	59.2	84.0	118	155	215			
38.5	56.8°	63.0°	69.0°	75.2°	80.2°	83.4°	87.1°	93.4°		
	23.2	35.0	48.2	67.0	87.0	105	131	177		
28.5	48.5°	54.3°	60.0°	64.2°	72.0°	78.0°	84.5°	93.0°		
	32.7	43.5	57.6	70.5	102	130	173	246		
25.5	41.0°	46.5°	53.8°	66.2°	74.7°	80.0°	86.0°	94.0°		
	28.3	38.0	54.3	91.0	134	170	216	296		
18.0	35.2°	42.0°	49.2°	58.0°	66.5°	74.2°	81.0°	88.5°	94.6°	
	34.0	47.5	67.5	99.0	132	200	254	333	421	
13.0	26.4°	34.3°	46.0°	55.5°.	65.6°	74.0°	82.3°	95.5°		
	24.7	37.0	65.0	101	155	215	301	432		
0.0	22.2°	26.0°	36.0°	45.2°	52.2°	62.0°	69.0°	73.8°	87.6°	94.6°
	25.5	32.2	52.0	76.0	108	161	214	294	422	524

TABLE 13

$SnCl_4 - HCOOC_4H_9$

SnCl4 content (in mole %)	Vapor pressure			Heat of evaporation (in kcal/mole)
	50°	70°	90°	
100.0	78.0	178	363	8.9
86.2	75.5	169	344	8.9
71.0	68.5	152	307	8.8
64.0	62.0	136	272	8.8
56.3	54.0	118	235	8.8
49.5	44.0	96.8	190	8.8
45.0	30.0	73.5	162	9.8
38.5	15.0	50.5	150	15.0
28.5	35.0	92.5	218	10.6
25.5	45.0	113	254	10.0
18.0	70.0	165	350	9.4
13.0	78.5	185	394	9.3
0.0	98.0	219	448	8.8

SUMMARY

1. In the systems formed by $HCOOC_4H_9$, $CH_3COOC_2H_5$, $C_2H_5COOC_2H_5$, $CH_3COOC_4H_9$, $C_2H_5COOC_4H_9$ and iso-$CH_3COOC_5H_{11}$ with stannic chloride, the partial vapor pressure of the stannic chloride shows an alternating, and the vapor pressure of the esters a negative, deviation from the additive line.

2. An interpretation is given for the course of the partial vapor pressure curves, and it is shown that the vapor pressure reflects the formation of compounds containing more than 2 molecules of ester per molecule of stannic chloride.

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VAPOR PRESSURE OF THE $SnCl_4 - CCl_3COOC_2H_5$ AND $SnCl_4 - C_6H_5OCH_3$ SYSTEMS

M. Usanovich and A. Dembitskii

Institute of Chemical Sciences, Academy of Sciences, KazSSR

In a previous work [1] it was reported that in the systems formed by stannic chloride with esters, the partial vapor pressure of stannic chloride shows alternating, and that of the esters negative, deviations from the additive lines due to the formation of the compounds $SnCl_4 \cdot 2RCOOR'$ and $SnCl_4 \cdot 3RCOOR'$ in these systems.

In the present communication, we present the results of studying the vapor pressure of the $SnCl_4-$ $-CCl_3COOC_2H_5$ and $SnCl_4-C_6H_5OCH_3$ systems. In contrast to those studied previously [1], these systems are characterized by the absence of electroconductivity, since, in them, the complex formation reaction stops at the stage of formation of compounds with a 1:2 composition [2,3]. Naturally, it was expected that this difference would be reflected on the vapor pressure diagrams also.

TABLE 1

$SnCl_4-C_6H_5OCH_3$

SnCl4 content (in mole %)	Boiling point (upper figures) Vapor pressure (mm Hg) (lower figures)									
100.0	9.6°	19.2°	29.5°	39.8°	50.9°	60.0°	70.0°	80.0°	90.1°	97.0°
	10.2	18.1	30.6	50.5	81.0	122	180	259	362	458
87.0	23.9°	30.4°	37.9°	48.6°	56.0°	65.1°	74.2°	83.4°	87.5°	94.3°
	21.5	30.5	44.3	70.0	100	144	199	283	331	409
71.0	24.9°	33.7°	41.5°	48.9°	56.5°	62.4°	68.6°	73.9°	79.3°	88.6° 95.9°
	20.8	32.8	47.0	65.5	91.5	117	149	181	224	309 393
60.0	28.3°	40.1°	49.5°	57.6°	66.5°	74.2°	80.5°	87.0°	96.5°	
	23.0	41.0	62.3	88.3	127	168	212	267	370	
50.0	21.8°	32.1°	41.1°	51.7°	61.3°	70.3°	77.8°	83.1°	95.0°	
	14.7	24.8	38.0	62.5	94.0	134	177	213	320	
40.5	31.1°	38.0°	50.0°	60.7°	70.5°	78.5°	84.9°	94.9°		
	21.2	30.5	52.5	82.0	122	166	206	289		
28.5	29.1°	38.6°	46.9°	55.2°	66.3°	76.4°	83.0°	88.3°	95.4°	
	11.5	25.5	37.0	54.5	86.5	129	164	198	252	
17.0	41.1°	45.9°	52.1°	57.5°	65.6°	74.7°	79.1°	87.1°	95.7°	
	21.5	27.5	37.5	47.5	67.0	96.5	114	154	209	
0.0	37.5°	50.0°	54.7°	60.5°	66.1°	70.2°	78.2°	85.1°	89.3°	96.4°
	8.0	15.0	19.0	26.0	34.0	41.5	57.5	78.0	92.0	121
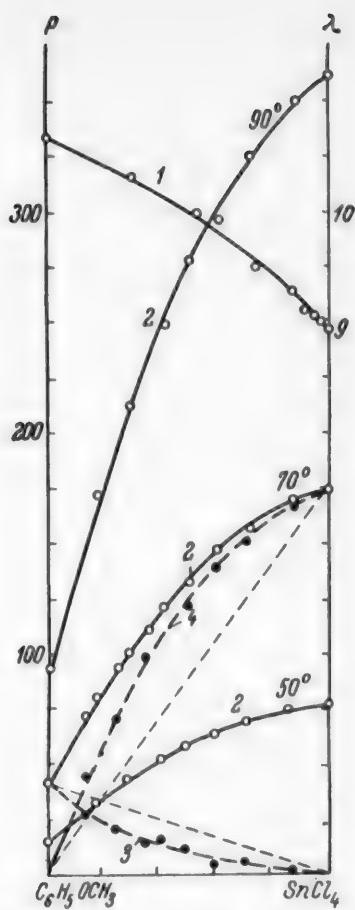
Fig. 1. Vapor pressure and heat of evaporation of
the SnCl$_4$–C$_6$H$_5$OCH$_3$ system: 1) heat of evapora-
tion; 2) total vapor pressure; 3) partial pressure
of C$_6$H$_5$OCH$_3$; 4) partial pressure of SnCl$_4$.
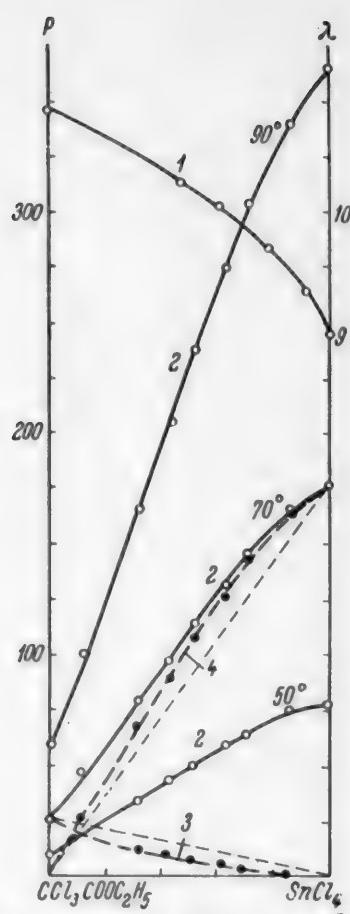
Fig. 2. Vapor pressure and heat of evaporation of
the SnCl$_4$–CCl$_3$COOC$_2$H$_5$ system: 1) heat of evapo-
ration; 2) total vapor pressure; 3) partial pressure
of CCl$_3$COOC$_2$H$_5$; 4) partial pressure of SnCl$_4$.

TABLE 2

SnCl$_4$–C$_6$H$_5$OCH$_3$

SnCl$_4$ content of mixture (in mole %)	Vapor pressure			SnCl$_4$ content of condensate (in mole %)	Partial vapor pressure		Heat of evaporation (kcal/ mole)
	50°	70°	90°		SnCl$_4$	C$_6$H$_5$OCH$_3$	
100.0	78.0	178	363	100.0	178	0	8.9
87.0	75.0	170	349	98.3	167	3.0	8.9
71.0	69.0	157	325	95.6	150	7.0	9.0
60.0	64.0	145	297	96.1	139.5	5.5	9.0
50.0	58.0	133	277	90.7	120.5	12.5	9.1
41.0	52.5	120	248	84.7	101.5	18.5	9.1
35.0	—	111	—	88.5	98.0	13.0	—
28.5	43.0	101	212	—	—	—	9.3
24.5	—	93.0	—	74.7	69.5	22.5	—
17.0	33.5	80.0	172	—	—	—	9.6
12.5	—	71.0	—	63.3	45.0	26.0	—
0.0	15.0	40.0	94.0	0	0	40.0	10.7

TABLE 3

SnCl$_4$–CCl$_3$COOC$_2$H$_5$

SnCl$_4$ content (in mole %)	Boiling point (upper figures) Vapor pressure (mm Hg) (lower figures)										
100.0 {	9.6°	19.2°	29.5°	39.8°	50.9°	60.0°	70.0°	80.0°	90.1°	97.0°	
	10.2	18.1	30.6	50.5	81.0	122	180	259	362	458	
86.0 {	22.5°	30.7°	41.3°	50.2°	56.7°	64.1°	70.0°	77.8°	84.9°	95.1°	
	19.8	29.5	50.0	75.5	99.5	134	167	225	287	402	
71.0 {	23.2°	31.5°	40.7°	52.3°	61.0°	70.0°	75.6°	82.8°	88.2°	94.2°	
	17.0	26.0	42.0	70.0	102	145	179	234	329	354	
63.0 {	23.5°	30.6°	38.7°	50.4°	59.1°	66.0°	70.0°	75.9°	81.6°	89.6°	96.3°
	15.5	23.0	34.5	58.5	86.5	113	133	166	203	270	337
43.0 {	28.0°	36.1°	46.0°	56.1°	64.9°	70.0°	77.1°	84.5°	95.3°		
	14.4	22.0	35.6	55.0	79.0	96.7	128	168	254		
31.5 {	27.7°	36.1°	44.1°	51.3°	58.6°	64.4°	70.0°	72.9°	79.7°	85.2°	94.3°
	11.3	16.8	25.0	35.0	47.5	61.5	78.0	88.0	114	139	194
11.5 {	31.4°	41.6°	49.0°	55.3°	61.5°	68.5°	75.6°	84.5°			
	7.3	12.3	17.8	24.0	31.6	42.8	58.8	84.0			
0.0 {	44.2°	57.3°	65.5°	72.4°	77.8°	84.3°	88.6°	95.2°			
	6.6	13.2	18.7	26.7	34.7	46.5	55.8	73.7			

TABLE 4

SnCl$_4$–CCl$_3$COOC$_2$H$_5$

SnCl$_4$ content of mixture (in mole %)	Vapor pressure			SnCl$_4$ content of mixture (in mole %)	Partial vapor pressure		Heat of evaporation (in kcal/mole)
	50°	70°	90°		SnCl$_4$	CCl$_3$COOC$_2$H$_5$	
100.0	78.0	178	363	100.0	178	0	8.9
86.1	74.5	165.5	340	99.5	164.5	1.0	8.9
71.0	63.0	145	303	99.0	143.5	1.5	9.0
63.0	58.0	132	275	95.5	126.0	6.0	9.0
52.0	49.0	113.5	238	94.8	107.5	6.0	9.2
43.0	42.0	97.0	205	89.8	87.5	10.0	9.2
31.5	33.0	77.5	166	86.7	67.5	11.0	9.4
11.6	18.5	45.5	102	62.7	28.5	17.0	9.9
0.0	9.0	24.5	59.0	0	0	24.5	10.9

EXPERIMENTAL

The ethyl trichloroacetate we synthesized was fractionally distilled. A fraction with b.p. 160.8° at 694 mm was collected and sealed in ampules; n^{20} 1.4508. "Pure grade" anisole was distilled twice, and a fraction with b.p. 151.2° at 698 mm collected; n^{20} 1.5170.

The working procedure was described in the previous article [1]. The results of measuring the vapor pressure of the stannic chloride—anisole system are presented in Tables 1 and 2; the results for the stannic chloride—ethyl trichloroacetate system are in Tables 3 and 4. Fig. 1 shows the isotherms of the total vapor pressure of the SnCl$_4$–C$_6$H$_5$OCH$_3$ system, and of the partial vapor pressures of the components at 70° and the curve for the dependence of the heat of evaporation on the vapor composition. Similar data for the SnCl$_4$–CCl$_3$COOC$_2$H$_5$ system are presented in Fig. 2. Figs. 1 and 2 show complete analogy in the behavior of the two systems. At all concentrations, the partial vapor pressure of stannic chloride is above the additive value. The partial vapor pressures of C$_6$H$_5$OCH$_3$ and CCl$_3$COOC$_2$H$_5$ are expressed by curves, which deviate negatively from the additive line along the whole of their course; close to 100% of stannic chloride, they merge into the abscissa. The total vapor pressure of the two systems and their heats of evaporation are characterized by positive deviations from the additive values.

A comparison of the data obtained with the results of investigating six systems formed by stannic chloride with various esters and possessing electroconductivity, shows essential differences between the first and the second. It is quite evident that in the two systems investigated in the present work, the interaction between the components is less than in the systems investigated previously [1].

The results obtained agree with the conclusions [2,3] that the compounds $SnCl_4 \cdot 2C_6H_5OCH_3$ and $SnCl_4 \cdot 2CCl_3COOC_2H_5$ are formed in the systems studied. This composition for the compounds formed requires [4] negative deviations for the partial vapor pressure of $C_6H_5OCH_3$ and $CCl_3COOC_2H_5$, and alternating ones for $SnCl_4$. The positive deviations of the partial vapor pressure of stannic chloride at all concentrations is apparently due to the appreciable volatility of the compounds formed.

SUMMARY

1. A study was made of the vapor pressure (total and partial) of the $SnCl_4-C_6H_5OCH_3$ and $SnCl_4-CCl_3COOC_2H_5$ systems.

2. The heats of evaporation of the systems investigated were calculated.

3. The results obtained confirm the existence of the compounds $SnCl_4 \cdot 2C_6H_5OCH_3$ and $SnCl_4 \cdot 2CCl_3COOC_2H_5$, which apparently have an appreciable vapor pressure.

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SPECTROPHOTOMETRIC INVESTIGATION OF REVERSIBLE AND IRREVERSIBLE CONVERSIONS OF IRON (III) SULFOPHTHALOCYANINE IN AQUEOUS SOLUTION

T. S. Glikman, M. E. Podlinyaeva and B. Ya. Dain

Institute of Physical Chemistry, Academy of Sciences, UkrSSR

Original article submitted May 12, 1958

Phthalocyanines are some of the few synthetic dyes whose structures are similar to natural pigments of the porphyrin class. In connection with this, many attempts have been made to use them as models of these pigments [1] for a more complete study of the behavior of compounds of this type under conditions when they are not bound to protein. There is particular interest in the study of iron phthalocyanines, which are close analogs of hemins, whose role in biological oxidation—reduction processes is well known. Sulfonated derivatives of these dyes, which are readily soluble in water, show a series of interesting peculiarities, stemming from their capacity for reversible and irreversible conversions, both under dark conditions and, especially, under the action of light. Since solutions of sulfonated derivatives of iron phthalocyanine are intensely colored, the spectrophotometric method is most convenient for studying them.

In the present article, we describe the results of a spectrophotometric investigation of the properties of aqueous solutions of these compounds and their conversion reactions, which were observed in these solutions.

EXPERIMENTAL

Preparation of Ferric Sulfophthalocyanine

Iron sulfophthalocyanines are the products of sulfonating phthalocyanine, in which the two central hydrogen atoms are replaced by ferric iron. The third valence of the iron is saturated with some monovalent anion. Iron (III) sulfophthalocyanine for the experiments was obtained by sulfonation of iron (III) phthalocyanine chloride by a modification of the method Linstead and Weiss developed for the synthesis of tetrasulfophthalocyanine [2].

5 g of unsulfonated iron (III) phthalocyanine chloride* was dissolved in small portions in 150 ml of fuming sulfuric acid (containing 28% excess SO_3). The mixture was heated at 78-80° for 1.5-2 hours. The sulfonation was considered complete when a drop of the sulfonation liquid, placed in water, dissolved without a precipitate. At the end of the sulfonation, the cold solution was carefully poured into a mixture of ice (~0.75 kg) and a saturated sodium chloride solution (~1.75 liters). The precipitate was collected by filtration, washed with NaCl solution, and then washed free from the latter, first with 75% and then with 90% alcohol until the disappearance of Cl^- ions. For some special experiments, the washing with alcohol was replaced by two reprecipitations of the product from aqueous solution with sodium chloride. The product was dried first in air at 105°, and then in vacuum at 60-65°.

Under the sulfonation conditions described, the iron was not removed from the complex. The residue after combustion of the product contained Fe_2O_3. In addition, aqueous solutions of the preparation did not give a

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*Unsulfonated iron (III) phthalocyanine chloride was synthesized according to the description presented in [3].
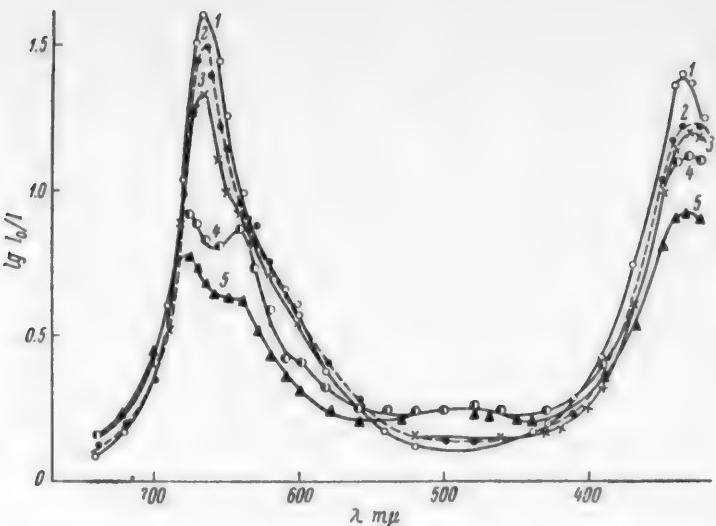
Fig. 1. Absorption curves of aqueous solutions of iron (III) sulfophthalocyanine at various pH values; pH values: 1) 10; 2) 8.2; 3) 6.0; 4) 3.8; 5) 2.0.
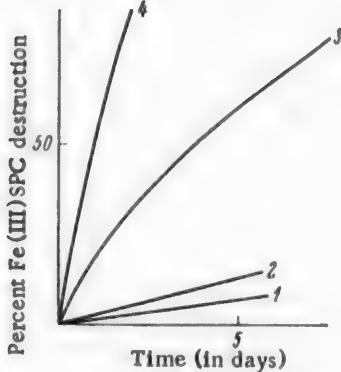
Fig. 2. Rate of iron (III) sulfophthalocyanine (Fe^{III}SPC) decomposition: 1) in water; 2) in 0.001 N NaOH; 3) in 0.1 N NaOH; 4) in 1 N NaOH.

reaction for ferric ions with potassium thiocyanate. This indicates that even after sulfonation the iron remains in the nucleus of the molecule. According to the iron content (5.04%), the product obtained was closest of all to the tetrasulfo derivative of iron phthalocyanine, i.e., was the sodium salt of ferric tetrasulfophthalocyanine. For brevity, this product will be referred to, subsequently, as iron (III) sulfophthalocyanine, or Fe^{III}SPC, and its ion* as [Fe^{III}SPC]$^+$.

Iron (III) sulfophthalocyanine was readily soluble in water and insoluble in anhydrous alcohol, ether, acetone, benzene, dioxane, etc. Its aqueous solutions had a blue color.

Equilibrium in Iron (III) Sulfophthalo-cyanine Solutions

Spectrophotometric investigation showed that aqueous solutions of ferric sulfophthalocyanine contained at least two absorbers, whose contents varied, depending on the pH of the medium. This is indicated by the changes in the absorption spectra observed in the experiment.

The absorption curves were plotted by means of an SF-4 spectrophotometer. The solutions were prepared in phosphate and borate buffers with pH values from 2 to 10. In all the experiments, the concentration of iron (III) sulfophthalocyanine was 0.16 g/liter. Measurements were made in the wavelength region from 325 to 800 mμ.

As the data in Fig. 1 show, the absorption curves of solutions with high pH values are characterized by two intense bands in the red and near-ultraviolet regions of the spectrum. One has a sharp maximum at 665 mμ and the other a somewhat broader maximum in the region of 330-338 mμ. As the pH of the medium falls, the intensity of the red band decreases and the band itself broadens slightly. At pH values less than 6, the maximum at 665 mμ disappears and is replaced by two new, quite close bands with absorption maxima in the regions of

* The designation [Fe^{III}SPC]$^+$ is taken for the ion since the charge from the central atom of iron equals +1.
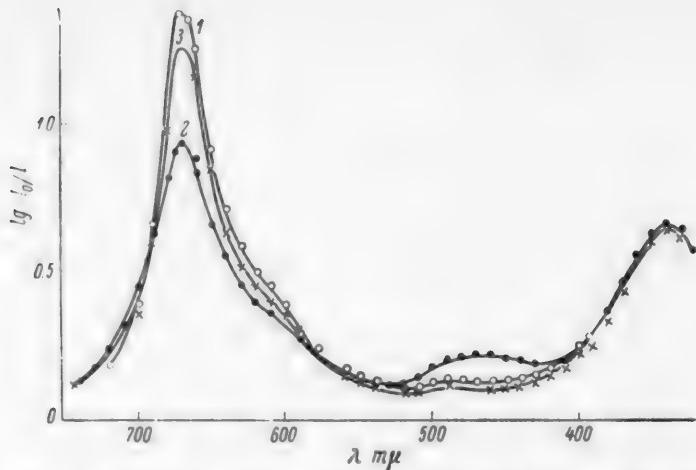
Fig. 3. Absorption curves of alkaline solutions of iron (III) sulfophthalo-
cyanine: 1) original solution; 2) after prolonged storage in the absence
of air; 3) after the admission of air.

655 and 675 mμ and a very weak, broad band appears in the section 450-550 mμ. A further reduction in the pH
leads to a slight increase in the intensity of this band. Simultaneously, the intensity of the red absorption bands
decreases.

The picture observed indicates that solutions of iron (III) sulfophthalocyanine are systems in a state of hy-
drolytic equilibrium:

$$[Fe^{III}SPC]^+ + H_2O \rightleftharpoons [Fe^{III}SPC]\,OH + H^+. \tag{1}$$

The red band with a maximum at 665 mμ, which appears most sharply with the medium pH at high values,
according to all the data, belongs to iron sulfophthalocyanine hydroxide $[Fe^{III}SPC]OH$. Changes in the spectrum
produced by an increase in the acidity of the solution, are the result of an increase in the concentration of the
second absorber, the hydrated ion $[Fe^{III}SPC]^+$, which is connected with displacement of process (1) to the left.
It is impossible to state more accurately which band belongs to the hydrated ion since, at pH < 2, side processes
of iron sulfophthalocyanine destruction proceed quite readily and are accompanied by precipitate formation.
The rate of the destructive process grows with an increase in the acidity of the medium.

Stability of Solutions

Iron (III) sulfophthalocyanine solutions were not only unstable in an acid medium. When stored in air,
neutral aqueous solutions slowly lost the intensity of their color. The rate of the decolorization process increased
with an increase in the alkalinity of the solution. However, this process was not accompanied by the formation
of a precipitate, as occurred in acid solutions. The effect of alkali concentration on the stability of $Fe^{III}SPC$
solutions is clearly shown by Fig. 2.

The changes in alkaline solutions described only occur in air. In the absence of air, changes also occur
in the spectrum of the solution, though these do not involve its decolorization. Thus, if the dissolved gases are
first carefully removed from an alkaline solution (0.2 N NaOH), and the latter is allowed to stand in a sealed
cell under dark conditions at room temperature, then, after several days the color of the solution changes from
blue to blue-green. The change in the absorption curve corresponds to this. The intensity of the red band falls
slightly, and simultaneously a low-intensity broad band, without a sharp maximum, appears in the region of 400
to 500 mμ. It is important to note that these changes are reversible in air. Contact with air leads to regenera-
tion of the original product; after a few minutes, the solution acquires its original blue color and the absorption
curve corresponds to that of the starting material in character. Only a fall in the absorption intensity of the solu-
tion over the whole region of the spectrum is observed, indicating the simultaneous occurrence of destruction of the
product (Fig. 3).
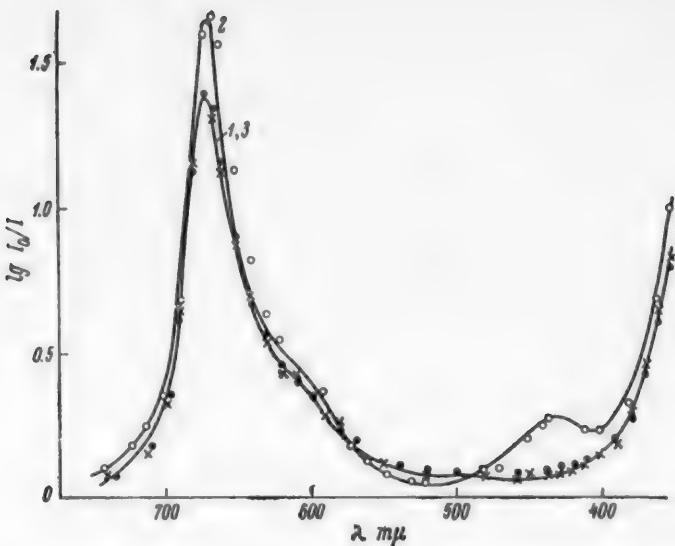
Fig. 4. Absorption curves of iron (III) sulfophthalocyanine in the presence of reducing agents: 1) original solution; 2) after the addition of ascorbic acid in the absence of air; 3) after the admission of air.

The nature of the spectral changes, which occur in degassed aqueous solutions, become more clear when we consider the effects which are observed during the action of reducing agents on solutions of iron (III) sulfophthalocyanine.

Action of Reducing Agents

Aqueous solutions of iron (III) sulfophthalocyanine react readily with various, and even extremely weak reducing agents. However, the character of the action of the latter depends on whether the experiments are performed in air or under vacuum conditions.

For experiments under vacuum conditions, a vessel was used, which made it possible to carry out all the necessary operations (plotting absorption spectra of the solutions, adding definite amounts of reducing agent after the plot, irradiation, heating, etc.) without breaking the vacuum. Degassing was carried out by many repetitions of the following operations: the solution was frozen, the gas above the solution pumped out on a high vacuum apparatus, and the solution then thawed. A more detailed description of the procedure is given in [4].

As the results of the experiments showed, the introduction of reducing agents into an aqueous solution of $Fe^{III}SPC$ under vacuum conditions produced the same qualitative changes as were observed on prolonged storage of degassed alkaline solutions. In the presence of reducing agents, however, these changes proceeded much more rapidly and were expressed more clearly. Thus, for example, the addition of ascorbic acid immediately produced a change in the color of a solution from blue to green. As in alkaline solutions not containing reducing agents, this corresponds to the appearance of a new band in the short-wave part of the spectrum, but with a narrower and more clearly expressed maximum, whose position at 430 mμ may be determined quite accurately in this case. A certain increase in the red band observed indicates that the product formed by the reduction of iron sulfophthalocyanine has a stronger absorption in this part of the spectrum in neutral and weakly acid media. Contact with air leads to complete regeneration of the original absorption curve, both in position and in intensity (Fig. 4). Reducing agents differing in strength (ascorbic acid, glucose, thiourea, Na_2S, $Na_2S_2O_3$, divalent tin ions and hydrogen-saturated palladium) produce the same qualitative effect. Similar effects were obtained when the experiments were performed in aqueous methanol solutions, where the methyl alcohol acted as the reducing agent. The difference in the nature of the reducing agents only affected the intensity and width of the short-wave band, and also the rate of formation of the reduced product, which varied from a few minutes (in the case of hydrosulfite and ascorbic acid) to several days (in 75% methyl alcohol).
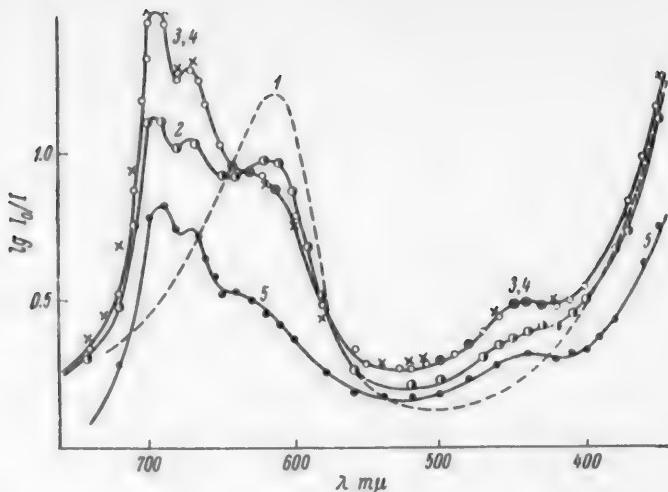
Fig. 5. Interaction of sulfophthalocyanine with $FeSO_4$ in an acid medium:
1) absorption of sulfophthalocyanine ($\sim 2 \cdot 10^{-4}$ m) with $FeSO_4$ added
($\sim 2 \cdot 10^{-3}$ m); 2) the same after 14 days; 3) the same after 30 days; 4)
the same after 40 days; 5) absorption of reduced form of iron sulfophthalo-
cyanine, obtained by the action of ascorbic acid on $Fe^{III}SPC$ in an acid
medium.

The effects given were only observed if the reducing agent was introduced into a solution that had first been degassed extremely carefully. In the presence of air, decolorization of the solution occurred in the same way as occurred on addition of alkali.

The analogy between the behavior of solutions under the action of reducing agents and of OH^- ions, and also the similarity in the character of the absorption spectra of the products thus formed, indicate that in the two cases the same product, namely, a reduced form of iron sulfophthalocyanine, is formed.

The formation of the reduced form of iron sulfophthalocyanine proceeds much more rapidly under the action of visible light. Thus, on irradiation of neutral aqueous methanol solutions, the reduction is complete after 4-5 hours instead of 2-3 days, required for this process in the dark. An analogous, though slightly weaker effect of the action of light is observed with alkaline solutions not containing special additives. In this case, the system contains essentially one absorber, iron (III) sulfophthalocyanine hydroxide, whose molecules undergo the primary photo act.

The Nature of the Reduced Form

There are, apparently, two possible directions for the reduction of iron sulfophthalocyanine. One of these should lead to a change in valence of the central iron atom ($Fe^{III} \rightarrow Fe^{II}$), and the other affects the organic part of the molecule's skeleton. In order to determine exactly which type of process occurred in the experiments described above, ferrous sulfophthalocyanine was obtained in solution, and its absorption spectrum was compared with the absorption curves of solutions obtained by the action of reducing agents on iron (III) sulfophthalocyanine.

No method for preparing ferrous sulfophthalocyanine is described in the literature. In the present work, it was obtained by the direct interaction of sulfophthalocyanine with ferrous sulfate.* To prevent oxidation of ferrous compounds, and suppress hydrolysis, the process was carried out in the absence of air in an acid medium. Under these conditions, the slow formation of ferrous sulfophthalocyanine occurred and was accompanied by an extensive change in the character of the absorption curve of the solution (Fig. 5). At room temperature, the

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*As is known, compounds of the porphyrin type containing Fe(II) [5] and other compounds related to iron (II) sulfophthalocyanine [6] are prepared analogously.
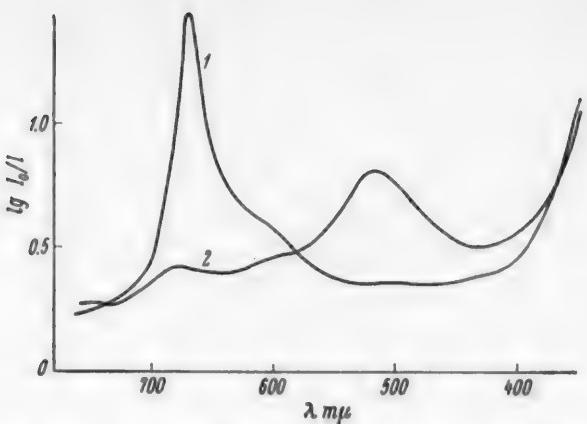
Fig. 6. Reduction of iron (III) sulfophthalocyanine in an alkaline medium:
1) absorption of $Fe^{III}SPC$ in 0.2 N NaOH; 2) the same after the addition
of excess glucose.

process was complete after 25-30 days (it proceeded in 1 hour at 70°). In the position of the maxima and the ratio of their intensities, the absorption curve of the final product coincided with the spectrum of the reduced form of iron sulfophthalocyanine, which was obtained by the action of ascorbic acid on $Fe^{III}SPC$ in an acid medium. The data presented give a basis for concluding that the reduction of iron (III) sulfophthalocyanine involves a change in valence of the central iron atom in the nucleus of the molecule.

By changing the reduction conditions, however, it was possible to obtain another type of reduced product. If an alkaline solution (0.2-0.3 N NaOH) of iron (III) sulfophthalocyanine is treated with excess reducing agent in an amount which exceeds the $Fe^{III}SPC$ content of the solution by 4-5 orders, then a red product is formed with one broad band with a maximum at 520 mμ (Fig. 6). The stage of green reduced form production usually precedes this. In air, the red form is readily oxidized to the original $Fe^{III}SPC$. Determining the nature of the red product requires an independent study, and was not part of the present investigation. We cannot exclude the possibility that during its formation, simultaneously with a change in the valence of the central iron atom, there is also a change in the organic part of the molecule. This is supported by the similarity of the absorption spectra of this product and the spectrum of the red reduced forms of chlorophyll and its close analogs, obtained in the work of Krasnovskii et al. [7].

DISCUSSION OF RESULTS

It can hardly be surmised that the ready conversion of iron (III) sulfophthalocyanine into the reduced form, observed in alkaline solutions, is connected with the dissociation of water. In analogy with the iron porphyrins, it should be assumed that the potential of the $Fe^{III}SPC/Fe^{II}SPC$ system is low [8]. It is most natural to assume, therefore, that the instability of iron sulfophthalocyanine solutions is connected with the interaction of the dye molecules with each other with the reduction of some molecules due to oxidation and destruction of others. The fact that noticeable formation of the reduced form is observed only in solutions with high pH values, indicates that in these processes a considerable part is played by the hydroxyl-containing molecules $[Fe^{III}SPC]OH$, which will be present in alkaline solutions in considerable amounts due to the equilibrium in process (1). It must be assumed that the behavior of the appropriate solutions described above is the result of the lability of the $[Fe^{III}SPC]OH$ molecules, which are capable of spontaneous decomposition with the formation of the OH radical and the reduced form $[Fe^{III}SPC]OH - Fe^{II}SPC + OH$.

The formation of free hydroxyls leads to destructive processes which slowly lower the concentration of dye in the solution.

This interpretation is supported especially by the fact that the rate of conversion of the oxidized form into the reduced one is increased by the action of light quanta on the corresponding systems. Actually, such

decomposition under the action of light is characteristic of hydroxy complexes of iron porphyrins and other compounds of the hemin type, as has already been shown in a series of works [9]. A conclusive demonstration of the spontaneous decomposition of hydroxyl complexes occurring in a solution of iron (III) sulfophthalocyanine is provided by experiments which make it possible to detect the presence of free radicals in the systems by the polymerization of methyl methacrylate, which they will cause. The results of these experiments,* carried out by a procedure which was described in detail previously [10], are presented below.

If alkaline solutions of $Fe^{III}SPC$, containing methyl methacrylate, and which have been degassed thoroughly in high vacuum, are irradiated and then left to stand in the dark, after 4-7 days (depending on the experimental ·conditions), a precipitate of polymer is produced. In unirradiated solutions, the precipitation of polymer begins much later. Control solutions, which did not contain pigment, and which were first irradiated (and also not irradiated), remained clear for a period of several months.

The instability of hydroxide complexes postulated here is, to some extent, characteristic of all compounds of the hemin type according to all the data. As has already been noted in photochemical investigations of analogous systems [9], it is the result of the rigidity of the organic skeleton of these compounds, which, according to the theoretical ideas of Libby [11], leads to a considerable reduction in the activation energy for intracomplex electron transfer. This explains the comparative ease with which electron transfer occurs in such systems, both in the light (due to the small quanta of the visible region of the spectrum), and in the dark.

Under normal conditions, the amount of free radicals in solutions of iron (III) sulfophthalocyanine in the stationary state must be extremely small, since, according to Frank and Rabinowitsch [12], a reverse act of primary recombination, characteristic of condensed systems, accompanies the decomposition act: $Fe^{II}SPC + OH \rightarrow$ $\rightarrow Fe^{III}SPCOH$.

Since the free hydroxyls formed will react with dye molecules destroying them, the original product regenerated after the admission of air will have a concentration lower than the original (Fig. 3).

It must be assumed that the oxidation of reducing agents introduced is largely accomplished by the action of free hydroxyls on them, also. Therefore, in the presence of reducing agents there will naturally be no noticeable destruction of the dye (Fig. 4).

These are the reasons for the instability of iron (III) sulfophthalocyanine solutions from which the air has first been removed. In continuous contact with air, the processes of reduced product formation, and its reverse oxidation to $Fe^{III}SPC$ proceed continuously. This creates conditions under which there is, likewise, continuous formation of free hydroxyls that destroy the organic material. Therefore, alkaline solutions stored in air are readily decolorized, and the more rapidly, the higher the hydroxyl ion concentration in the solution. Naturally, such a process of destruction and decolorization proceeds particularly readily in light.

SUMMARY

By a spectrophotometric method, it was shown that aqueous solutions of iron (III) sulfophthalocyanine are systems in a state of hydrolytic equilibrium. Iron (III) sulfophthalocyanine hydroxide, formed by hydrolysis, is unstable and slowly decomposes with the formation of iron (II) sulfophthalocyanine and free hydroxyl. This process is accelerated by the action of visible light. The formation of free radicals during the storage of degassed solutions of iron (III) sulfophthalocyanine was confirmed by the initiation of polymerization chains. Spontaneous decomposition of the hydroxide is the reason for the instability of aqueous solutions of ferric sulfophthalocyanine and their slow decolorization in the presence of air.

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PHYSICOCHEMICAL INVESTIGATION OF THE HYDRAZINE — ACETIC ACID BINARY SYSTEM

I. M. Bokhovkin

Archangel Wood Technology Institute

Original article submitted May 29, 1958

The literature contains comparatively little data on physicochemical analysis of binary salts formed by hydrazine with organic acids [1], although these investigations are of undoubted practical and theoretical interest.

Hydrazine is characterized by a nuclear separation of d(NN) = 1.47 A and considerable polarity with a dipole length of 0.38 A. It is readily soluble in water. In addition, hydrazine is characterized by a high dielectric permeability (53 at 23°) and, therefore, must be a readily ionizing solvent for many inorganic and also organic substances. On solution of organic acids in hydrazine, there must be an increase in the electrolytic dissociation of the former. Being a good complex-former, the hydrogen ion must facilitate the formation of compounds between the acids and hydrazine in the same way as occurs in the solution of organic acids in acetamide [2,3], which has a dielectric permeability of 59.1.

TABLE 1

Density (d), Surface Tension (σ), and Viscosity (η) of the Hydrazine—Acetic Acid System

Composition (in mole %)		d, (g/cm^3)			σ (dyne/cm)			η (centipoises)		
N_2H_4	CH_3COOH	70°	75°	80°	70°	75°	80°	70°	75°	80°
90.0	10.0	1.044	1.040	1.035	56.7	56.2	55.9	1.018	0.934	0.848
80.0	20.0	1.082	1.078	1.074	55.6	54.9	54.4	1.900	1.652	1.437
70.0	30.0	1.109	1.107	1.104	53.6	53.1	—	2.523	2.182	1.801
60.0	40.0	1.140	1.138	1.136	51.3	50.9	50.6	6.267	5.001	3.876
50.0	50.0	—	—	—	—	—	—	11.414	8.642	6.652
52.0	48.0	1.159	1.153	1.149	45.9	45.4	45.1	—	—	—
40.0	60.0	1.142	1.138	1.132	37.0	36.8	36.4	—	—	—
38.2	61.8	—	—	—	—	—	—	8.009	5.809	4.431
30.0	70.0	1.125	1.118	1.111	33.4	33.2	33.0	5.372	4.200	3.081
20.0	80.0	1.097	1.091	1.086	29.3	29.0	28.7	2.937	—	1.998
10.0	90.0	1.063	1.060	1.053	—	—	—	1.389	1.220	1.052
	100.0				22.6	22.2	21.8	0.535	0.493	0.460

This article is devoted to a description of the results we obtained in a physicochemical investigation of the density, viscosity, surface tension, and specific electroconductivity of the hydrazine—acetic acid system.

EXPERIMENTAL

Hydrazine was obtained by dehydration of its monohydrate in a stream of nitrogen [4], and was purified by three distillations. The acetic acid was purified by freezing. After purification, the hydrazine and acetic acid had constants, which agreed well with those reported in the literature. The solutions were prepared by weight, and their compositions are expressed in molar percents. Measurements were made at 70, 75, and 80°. The temperature in the thermostat was maintained with an accuracy of ± 0.2°. The viscosity was determined by means of an Ostwald viscometer.
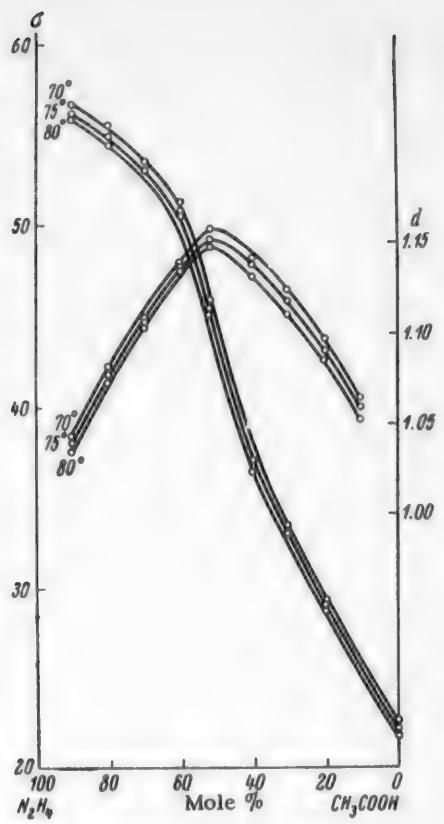
Fig. 1. Surface tension (σ) and density ($\underline{d}$) of the hydrazine−acetic acid system.
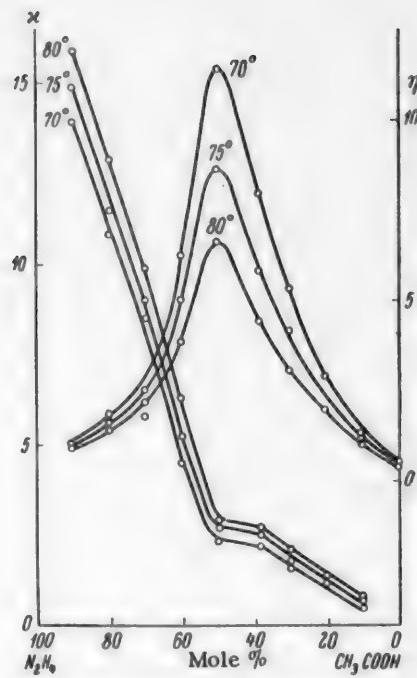
Fig. 2. Specific electroconductivity (κ) and viscosity (η) of the hydrazine−acetic acid system.

TABLE 2

Specific Electroconductivity (κ), Reduced Electroconductivity ($\eta\kappa$) and Temperature Coefficients of Electroconductivity (α) and of Viscosity (β) of the Hydrazine−Acetic Acid System

Comp. (mole %)		κ (ohm$^{-1} \cdot$ cm^{-1})			$\eta\kappa$			α		β	
N_2H_4	CH_3COOH	70°	75°	80°	70°	75°	80°	from 70−75°	from 70−80°	from 70−75°	from 70−80°
90.0	10.0	0.140	0.150	0.159	0.1425	0.140	0.1348	1.379	1.271	1.7213	1.8210
80.0	20.0	0.108	0.115	0.129	0.2052	0.1899	0.1854	1.233	1.772	2.2793	2.775
70.0	30.0	0.085	0.090	0.099	0.2145	0.1964	0.1783	1.143	1.522	2.899	3.340
60.0	40.0	0.045	0.052	0.063	0.2820	0.2601	0.2442	2.887	3.333	4.494	4.715
50.0	50.0	0.023	0.027	0.029	0.2625	2.2333	0.1929	3.200	2.308	5.529	5.272
38.2	61.8	0.022	0.025	0.027	0.1762	0.1452	0.1196	2.553	2.041	6.369	5.724
30.0	70.0	0.016	0.018	0.021	0.0960	0.0756	0.0647	2.353	2.703	4.898	2.269
20.0	80.0	0.012	0.013	0.014	0.0352		0.0280	1.600	1.536	—	4.695
10.0	90.0	0.005	0.007	0.008	0.0069	0.0085	0.0084	6.666	4.611	2.591	2.763

The electroconductivity was measured by Kohlrausch's method in a closed vessel with smooth platinum electrodes. The surface tension was investigated by means of the greatest pressure of gas (air) bubbles [5]. The vessel for the investigation was of the closed type. Mercury was used as the sealing liquid between the cap with a capillary tip , and the vessel. The density was determined by hydrostatic weighing. Platinum was used as the body for weighing.

Fig. 3. Reduced electroconductivity ($\varkappa\eta$) and temperature coefficients of electroconductivity (α) and viscosity (β) of the hydrazine—acetic acid system.

There are no data in the literature on the melting point of the hydrazine—acetic acid system. We were unable to investigate the melting point of this system in our laboratory due to the low freezing points of the solutions.

The results of determining the density of the hydrazine—acetic acid system are presented in Table 1 and in Fig. 1. The density isotherms were curves with a sharply expressed maximum, corresponding to a component ratio of 1:1. Surface tension measurement data are presented in Table 1 and Fig. 1. The surface tension isotherms had an S-shaped form, which fell sharply from hydrazine to acetic acid at component ratios close to 1:1. The results of the viscosity measurements are presented in Table 1, and are illustrated graphically in Fig. 2. The viscosity isotherms had a maximum at 50 mole% of hydrazine. Data on the measurement of the specific electroconductivity are presented in Table 2 and in Fig. 2. The electroconductivity fell sharply from hydrazine to 50 mole% of acetic acid. There was then a sharp change in the direction of the electroconductivity isotherms, which fell more smoothly toward acetic acid.

DISCUSSION OF RESULTS

The presence of sharply expressed maxima on the density and viscosity isotherms indicate the formation and existence of compounds in the homogeneously fused medium of the hydrazine—acetic acid system. In addition, the form of the viscosity indicates that the stability of the compound depends on temperature. Thus, at 70°, the compound is stable and the viscosity curve has a quite sharp maximum. With an increase in temperature of 10°, the viscosity decreases by a factor of two, and the maximum flattens out, indicating dissociation of the compound in the homogeneous fused medium. The S-shape of the surface tension isotherm is also an indication of the existence of the compound $N_2H_4 \cdot CH_3COOH$.

The specific electroconductivity isotherms have a sharp inflection at the compound $N_2H_4 \cdot CH_3COOH$. To elucidate the effect of viscosity on electroconductivity, we recalculated the latter. Fig. 3 shows that the reduced electroconductivity isotherms pass through a sharp maximum approximately at a component ratio of 1:1. We also calculated the temperature coefficients of electroconductivity over the temperature ranges 70-75 and 70-80° (Table 2). The curves of the electroconductivity temperature coefficients (α) are illustrated in Fig. 3. They have a maximum corresponding to the compound $N_2H_4 \cdot CH_3COOH$. Due to their negative values, the viscosity temperature coefficients are plotted below the zero line for this property. The viscosity temperature coefficient (β) curves are illustrated in Fig. 3. They have a minimum corresponding to a 1:1 compound.

Thus, all the properties we studied indicate the existence of a compound between hydrazine and acetic acid. Assuming that this compound is formed by a type of hydrogen bond, its structure may be expressed in the following way:

THE HEATS OF HYDRATION OF $Me(H_2O)_6^{+2}$ IONS

S. N. Andreev, V. G. Khaldin and E. V. Stroganov

Leningrad State University

Original article submitted May 30, 1958

The investigation of the hydrate sheaths of ions in solution remains one of the most difficult problems in chemistry, up to the present time. The main reason for this is the absence of physicochemical methods for the direct study of the state of the H_2O molecules, forming the closest surroundings of the ions, isolated from the whole mass of solvent. To a considerable extent, such investigations are complicated by the multiplicity of the chemical properties of ions, as a result of which the character of the interaction of ions with water, and the structure of the hydrate sheaths of the ions, changes in an extremely complex way, depending on the chemical nature of the ions.

The solution of this problem would be facilitated to a considerable extent by a thorough study of the properties of aquo ions forming the crystal lattice of crystalline hydrates of various salts, and an investigation of the properties of H_2O molecules, forming the closest surroundings of the ions in crystalline hydrates.

An investigation of some crystalline hydrates, carried out by K. B. Yatsimirskii [1-5], shows that for the ions Mg^{+2}, Zn^{+2}, Mn^{+2}, Co^{+2}, and Ni^{+2}' the energy of addition of six H_2O molecules to the Me^{+2} ion and the heat of hydration of $Me(H_2O)_6^{+2}$ ions not only have high numerical values, but are also similar in value. On the basis of data presented in the works of K. B. Yatsimirskii, it may be stated that the heat of hydration of the aquo ions $Me(H_2O)_6^{+2}$ is approximately half of the heat of hydration of the Me^{+2} ion. It is important to note the fact that this conclusion, based on experimental data, is in agreement with data on the heats of hydration of the ions K^+, Rb^+, Cs^+, Cl^-, Br^-, and I^-, obtained in the calculations of K. P. Mishchenko and A. M. Sukhotin [6]. In addition, from the point of view of a simplified hypothesis on the process of ion hydration, such a large value for the heats of hydration for the aquo ions $Me(H_2O)_6^{+2}$ seems unusual. Actually, according to the data of K. B. Yatsimirskii, the heat of hydration of the ions $Me(H_2O)_6^{+2}$ is equal to 220-240 kcal, i.e., almost equal to the heat of hydration of a proton, and approximately twice as great as the heat of hydration of Li^+ and F^- ions. This makes further study of the heats of hydration of $Me(H_2O)_6^{+2}$ aquo ions necessary. The subject of such an examination should be crystalline hydrates, which have been thoroughly studied from the point of view of the structures of their crystal lattices, since only data from x-ray structural analysis gives sufficient grounds for proposing the presence of the aquo ions $Me(H_2O)_6^{+2}$ in the molecule of crystal hydrates [7,8]. The energy of addition of six H_2O molecules to Me^{+2} ions, and also the heat of hydration of the aquo ions $Me(H_2O)_6^{+2}$ may be calculated if we know the first integral heats of solution and the crystal lattice energies of the salts containing the $Me(H_2O)_6^{+2}$ ions.

The crystal lattice structures of the hexahydrates of Mg^{+2}, Zn^{+2}, Cd^{+2}, Mn^{+2}, Fe^{+2}, Co^{+2} and Ni^{+2} perchlorates have been investigated thoroughly by West [9]: all six of the H_2O molecules in these compounds form the closest surroundings of the Me^{+2} cations in the form of a right octahedron, giving grounds for stating that $Me(H_2O)_6^{+2}$ ions exist in the structure of the molecule of these crystal hydrates. A. F. Kapustinskii's equation [10] makes it possible to calculate with great accuracy the crystal lattice energy of salts formed by the simplest ions.

The possibility of using this equation for calculating the energy of crystal lattices formed by complex ions, with the form of right octahedra or tetrahedra, may be demonstrated by comparison of the crystallochemical radii of these ions, found from the data of x-ray structural analysis of the complex salts, with the radii of the same ions, calculated by means of A. F. Kapustinskii's equation from the heats of formation of these salts.

TABLE 1

Crystal Lattice Energy of the Crystal Hydrates $Me(ClO_4)_2 \cdot 6H_2O$

Formula of crystal hydrate	Crystallo-chemical radius of aquo ion (A) [9, 11]	Crystal lattice energy (kcal/mole)
$Mg(ClO_4)_2 \cdot 6H_2O$	2.31	349
$Zn(ClO_4)_2 \cdot 6H_2O$	2.30	350
$Cd(ClO_4)_2 \cdot 6H_2O$	2.42	342
$Mn(ClO_4)_2 \cdot 6H_2O$	2.36	346
$Fe(ClO_4)_2 \cdot 6H_2O$	2.33	348
$Co(ClO_4)_2 \cdot 6H_2O$	2.30	350
$Ni(ClO_4)_2 \cdot 6H_2O$	2.29	351

TABLE 2

Integral Heats of Solution at 25° of the Crystal Hydrates $Me(ClO_4)_2 \cdot 6H_2O$

Formula of crystal hydrate	ΔH of solution (in kcal/mole)		
	molar dilution 1 : 200	molar dilution 1 : 500	molar dilution 1 : 1000
$Zn(ClO_4)_2 \cdot 6H_2O$	1.9	1.6	1.5
$Cd(ClO_4)_2 \cdot 6H_2O$	0.6	0.4	0.4
$Mn(ClO_4)_2 \cdot 6H_2O$	1.4	1.0	1.0
$Fe(ClO_4)_2 \cdot 6H_2O$	1.8	1.5	1.4
$Co(ClO_4)_2 \cdot 6H_2O$	1.9	1.6	1.6
$Ni(ClO_4)_2 \cdot 6H_2O$	2.4	2.0	2.0

TABLE 3

$\Delta H°$ of Formation of Crystal Hydrates $Me(ClO_4)_2 \cdot 6H_2O$, $\Delta H°$ of Formation of the Aquo Ions $Me(H_2O)_6^{+2}$. Heats of Hydration of the Ions Me^{+2} and $Me(H_2O)_6^{+2}$

Formula of crystal hydrate	$\Delta H°$ of formation of the crystal hydrate (kcal/mole)	ΔH of formation of the ion $Me(H_2O)_6^{+2}$ (kcal/g-ion)	Energy of addition of $6H_2O$ gas (in kcal/g-ion) our data	Energy of addition of $6H_2O$ gas (in kcal/g-ion) data of [1-5]	Energy of formation of aquo ion from Me^{+2} and H_2O liquid (kcal/g-ion)	Heat of hydration of aquo ion $Me(H_2O)_6^{+2}$ (kcal/g-ion)	Heat of formation of ion Me^{+2} (kcal/g-ion)
$Mg(ClO_4)_2 \cdot 6H_2O$	−583.2	−74	289	300	226	240	466
$Zn(ClO_4)_2 \cdot 6H_2O$	−510.6	−1	319	331	256	239	495
$Cd(ClO_4)_2 \cdot 6H_2O$	−490.4	12	269	—	206	232	438
$Mn(ClO_2)_2 \cdot 6H_2O$	−526	−20	275	288	211	235	446
$Fe(ClO_4)_2 \cdot 6H_2O$	−495	13	294	—	288	237	525
$Co(ClO_4)_2 \cdot 6H_2O$	−490.4	20	321	324	258	240	498
$Ni(ClO_4)_2 \cdot 6H_2O$	−490	21	333	329	270	239	509

Table 1 gives the values of the crystal lattice energies of the crystal hydrates $Me(ClO_4)_2 \cdot 6H_2O$, which we calculated from A. F. Kapustinskii's equation. In accordance with the data of Bedtker and Hassel [11], the radius of the ClO_4^- ion was taken as equal to 2.36 A in this calculation.

We measured the first integral heats of solution in H_2O of the hexahydrates of Zn^{+2}, Cd^{+2}, Mn^{+2}, Co^{+2} and Ni^{+2} perchlorates on samples prepared by the action of $HClO_4$ (analytical grade) on carbonates of the appropriate metals. The purity of the samples obtained was ensured by three recrystallizations from water and drying over H_2SO_4 to a composition corresponding to the formula $Me(ClO_4)_2 \cdot 6H_2O \pm 0.05H_2O$.

$Fe(ClO_4)_2 \cdot 6H_2O$ was prepared by dissolving Armco iron in 15-20% $HClO_4$ and then precipitating impurities with hydrogen sulfide. The preparation was recrystallized and dried over H_2SO_4 in a manipulator filled with CO_2.

The heats of solution of the crystal hydrates at molecular dilutions of 1:200, 1:500, and 1:1000 were measured at 25° in a microcalorimeter, constructed according to the plan proposed by K. P. Mishchenko [12]. The sensitivity of the calorimeter was 0.0254 ± 0.0002 cal. Data on the integral heats of solution of the crystal hydrates listed are presented in Table 2.

As can be seen from Table 2, the integral heats of solution at molecular dilutions of 1:500 and 1:1000 differ insignificantly and the first integral heats of solution of the aquo complexes considered can be taken as equal to the integral heats of solution at a molecular dilution of 1:1000 with little error. We took data on the heats of solution of $Mg(ClO_4)_2 \cdot 6H_2O$ from the summary of Rossini, Wagman et al. [13].

The values of the standard heats of formation of the crystal hydrates ($\Delta H°$), calculated from the first integral heats of solution, are presented in Table 3.

Knowing the heat of formation of the ion ClO_4^- in the gas phase [14], and the value of the crystal lattice energies of the crystal. hydrates with the formula $Me(ClO_4)_2 \cdot 6H_2O$, it was not difficult to calculate the heats of formation of the aquo ions $Me(H_2O)_6^{+2}$, the energy of the process $Me_{gas}^{+2} + 6H_2O_{gas} = Me(H_2O)_6^{+2}{}_{gas}$, and the energy of formation of the aquo ions $Me(H_2O)_6^{+2}$ from Me_{gas}^{+2} ions and liquid H_2O. The figures we calculated for these values are compared with the data of K. B. Yatsimirskii in Table 3. The same table gives the heats of hydration of the aquo ions $Me(H_2O)_6^{+2}$, which we calculated from Fajans' equation. In this calculation, the heat of hydration of the ClO_4^- ion was taken as 55 kcal/ion.

Our data differ somewhat from the data of K. B. Yatsimirskii. The reason for this difference lies only in the fact that in our calculations we used the heats of formation of the ions Me_{gas}^{+2} and the values of the heats of formation of anions in aqueous solution taken from the summary of Rossini et al. [13], of 1952. K. B. Yatsimirskii used values taken from the summary of Bichowsky and Rossini of 1936, in his calculations.

Thus, a thermochemical consideration of the crystal hydrates of Mg^{+2}, Zn^{+2}, Cd^{+2}, Mn^{+2}, Fe^{+2}, Co^{+2} and Ni^{+2} perchlorates, which are typical aquo complex compounds of the form $[Me(H_2O)_6](ClO_4)_2$, confirms the data established by K. B. Yatsimirskii. The heat of hydration of the aquo ions $Me(H_2O)_6^{+2}$ actually equals approximately half the heat of hydration of Me^{+2} ions.

The reason for such a high value for the heat of hydration of $Me(H_2O)_6^{+2}$ ions, in our opinion, may lie, for example, among the following.

1. It is possible that in the formation of a dilute solution from the crystal hydrate $Me(ClO_4)_2 \cdot 6H_2O$ in liquid H_2O, the hydrate sheath of the aquo ions $Me(H_2O)_6^{+2}$ is completely reconstructed, and the coordination number of the Me^{+2} ions changes [15, 16].

2. H_2O molecules in the aquo ion $Me(H_2O)_6^{+2}$ are strongly polarized. The interaction of the hydrogen atoms of these water molecules with the solvent may be accompanied by a large exothermal effect.

3. The aquo ions $Me(H_2O)_6^{+2}$ are aquo acids [17-19]. The value of the heat of hydration of these ions, calculated by Fajans' equation, includes the energy of protolytic dissociation of the aquo ions.

We consider it our pleasant duty to express our deep thanks to A. F. Kapustinskii and K. P. Mishchenko for valuable critical comments on this work.

SUMMARY

1. From the first integral heats of solution of crystal hydrates of metal perchlorates, we calculated the standard values of the heats of formation of: $Zn(ClO_4)_2 \cdot 6H_2O$, $Cd(ClO_4)_2 \cdot 6H_2O$, $Mn(ClO_4)_2 \cdot 6H_2O$, $Fe(ClO_4)_2 \cdot 6H_2O$, $Co(ClO_4)_2 \cdot 6H_2O$ and $Ni(ClO_4)_2 \cdot 6H_2O$.

2. From A. F. Kapustinskii's equation we calculated the values of the crystal lattice energies of the crystal hydrates of Mg, Zn, Cd, Mn, Fe, Co and Ni. perchlorates.

3. Calculations were made of the heats of formation of the aquo ions $Mg(H_2O)_6^{+2}$, $Zn(H_2O)_6^{+2}$, $Cd(H_2O)_6^{+2}$, $Mn(H_2O)_6^{+2}$, $Fe(H_2O)_6^{+2}$, $Co(H_2O)_6^{+2}$, and $Ni(H_2O)_6^{+2}$, the energies of water addition to Me^{+2} ions in the gas phase, and the heats of hydration of the ions $Me(H_2O)_6^{+2}$. The calculated values confirmed the data of K. B. Yatsimirskii.

4. It was shown that the heats of hydration of the aquo ions $Me(H_2O)_6^{+2}$ are approximately half of the heat of hydration of the ions Me^{+2}. An explanation was proposed for the large numerical values of the heats of hydration of the aquo ions considered.

<div align="center">LITERATURE CITED</div>

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DERIVATIVES OF m- AND p-BENZENEDISULFONIC ACIDS

A. V. Kirsanov and N. A. Kirsanova

Institute of Organic Chemistry, Academy of Sciences, UkrSSR

Original article submitted May 20, 1958

Benzenedisulfonic acids have been known for more than 80 years [1], but many of their simplest derivatives (for example, the dimethyl and diethyl esters of m- and p-benzenedisulfonic acids, their N-substituted amides, etc.), have not been prepared up to the present time. Not one phosphorus-containing derivative of these acids was known, although such compounds are of undoubted interest, not only as new substances, but also as possible insecticides. In addition, derivatives of p-benzenedisulfonic acids are of interest as potential raw materials for high-molecular substances of new types. Therefore, the study of the chemistry of the simplest p-benzenedisulfonic acid derivatives was of especial interest.

The aim of the present work was the preparation of certain of the simplest derivatives of m- and p-benzenedisulfonic acids and, incidentally, m,m'-diphenyl sulfone disulfonic acid,and the study of their properties.

The methyl and ethyl esters of m- and p-benzenedisulfonic acids and m,m'-diphenyl sulfone disulfonic acid were obtained by the action of a benzene solution of the appropriate dichloride on solutions of sodium alcoholates, which were first evaporated to a thick sirup in vacuum. With the use of dry, or almost dry, sodium alcoholates, the reaction hardly proceeded at the boiling point of benzene, but in the presence of appreciable amounts of alcohol, the reaction proceeded readily, but the diesters could not be isolated, since the diesters of benzenedisulfonic acids are strong alkylating agents (see below) and, therefore, reacted comparatively readily with the excess alcohol. Thus, the reaction proceeded by the scheme:

$$C_6H_4(SO_2Cl)_2 + 2RONa \longrightarrow 2NaCl + C_6H_4(SO_2OR)_2;$$
$$C_6H_4(SO_2OR)_2 + ROH \longrightarrow ROR + C_6H_4(SO_2OR)SO_2OH.$$

If there was little alcohol in the reaction mixture, then the second reaction of the scheme proceeded slowly and it was possible to isolate the diester before it could be alcoholyzed. If there was a lot of alcohol in the reaction mixture, the second reaction of the scheme proceeded very rapidly and the diester could not be isolated.

The methyl and ethyl esters of m- and p-benzenedisulfonic acids and m,m'-diphenyl sulfone disulfonic acid were colorless, comparatively low-melting crystalline substances. For all three acids, the methyl esters melted appreciably higher than the ethyl esters. The esters of m-benzenedisulfonic acid melted below the esters of the p-disulfonic acid and the latter below the esters of m,m'-diphenyl sulfone disulfonic acid. The yields and properties of the esters are presented in Table 1.

The dimethyl and diethyl esters were rapidly hydrolyzed when heated with water. It seemed interesting to determine the extent of the alkylating properties of the diesters. For this purpose, we used the procedure developed in detail by A. I. Kiprianov and A. I. Tolmachev [2], and based on determining the rate of alkylation of 2-methylbenzthiazole. It was found that the rate constants for forming quaternary salts of 2-methylbenzthiazole (which determine the alkylating capacity) were $12.2 \cdot 10^{-5}$ and $9.54 \cdot 10^{-5}$ for the methyl esters of m- and p-benzenedisulfonic acids at 90°, i.e., considerably higher than the constants of methyl iodide, methyl p-toluenesulfonate, and methyl benzenesulfonate [2], but considerably less than the constants of methyl nitrobenzenedisulfonates and dimethyl sulfate, not to speak of the methyl esters of nitro- and nitrochlorobenzenesulfonic acids [2].

TABLE 1

Esters of Disulfonic Acids of the Type Ar(SO₂OR)₂

Ar	R	Yield (in %)	Melting point	External appearance; recrystallization solvent	S content (in %)	Empirical formula	Calc. S content (in %)	Solubility* water	alcohol	benzene	carbon tetrachloride	ether	petroleum ether
m-C₆H₄	CH₃	61.1	52—54°	Prisms; ether	24.22, 24.40	$C_8H_{10}O_6S_2$	24.06	‖	++	+	‡	‡	+
m-C₆H₄	C₂H₅	75.2	Liquid	Liquid	21.66, 21.90	$C_{10}H_{14}O_6S_2$	21.77	‖	++	+	‡	+	‡
p-C₆H₄	CH₃	88.1	111—113	Plates; alcohol	24.03, 24.23	$C_8H_{10}O_6S_2$	24.06	‖	‡	++	+	+	+
p-C₆H₄	C₂H₅	66.4	99—100	Plates; CCl₄	21.99, 21.98	$C_{10}H_{14}O_6S_2$	21.77	‖	+	+	+	‡	‡
m-SO₂(C₆H₄)₂	CH₃	71.5	121—123	Prisms; methanol	23.81, 23.77	$C_{14}H_{14}O_8S_3$	23.66	‖	+	++	‖	‖	‖
m-SO₂(C₆H₄)₂	C₂H₅	42.0	82—84	Prisms; methanol	see [3]	$C_{16}H_{18}O_8S_3$	22.10	‖	+	++	‖	‖	‖

*Here and below, the following designations have been adopted: insoluble at boiling point (=), sparingly soluble at boiling point (‖), readily soluble at boiling point (−), readily soluble at 20° (+), readily soluble at 20° (‡). All the substances dissolved in acetone readily at 20°.

It is very interesting that dimethyl m-benzenedisulfonate (constant at 90°, $12.2 \cdot 10^{-5}$), is more active than dimethyl p-benzenedisulfonate (constant at 90°, $9.54 \cdot 10^{-5}$). Consequently, the effect of one sulfonic acid group on another is largely transmitted by an induction and not an electromeric effect, as is also the effect of a nitro group on a sulfonic group, according to the experiments of Kiprianov and Tolmachev [2]. Since dimethyl m- and p-benzenedisulfonates are strong methylating agents, it is quite understandable that their preparation should be carried out in the presence of the least possible amount of alcohol, which is alkylated quite rapidly by these esters (see above).

Diamides of aromatic disulfonic acids have already been known for a long time [1,4]. Tetramethyl- and tetraethyldiamides of disulfonic acids were unknown up to now. They are interesting as undescribed simple derivatives of aromatic disulfonic acids and as possible physiologically active substances, since the accumulation of dialkylamido groups in a molecule frequently leads to an increase in physiological activity. Actually, they were all found to be contact insecticides, but of low activity. Up to now, there has been no report in the literature that dialkylamides of sulfonic acids may have insecticide properties.

The tetramethyl- and tetraethyldiamides of m- and p-benzenedisulfonic acids and m,m'-diphenyl sulfone disulfonic acid, and the unsymmetrical dimethyl- and diethyldiamides of p-benzenedisulfonic acid were obtained by the usual scheme by the action of amines on the sulfonyl chlorides. The yields and properties of the N-alkylated disulfonamides are presented in Table 2.

The tetramethyl- and tetraethyldiamides of the disulfonic acids were colorless crystalline substances with a neutral character. The unsymmetrical dialkylamides of p-benzenedisulfonic acid had weakly acidic properties and dissolved readily in aqueous solutions of caustic alkalis. They were precipitated unchanged from such solutions by the action of acids, including carbon dioxide. They were hydrolyzed with difficulty.

A large number of phosphorus-containing derivatives of amides of monosulfonic acids of the acyclic and cyclic series are known, and

TABLE 2

N-Alkylated Diamides of Disulfonic Acids of the Type $R'_2NSO_2ArSO_2R''$:

Ar	R'	R''	Yield (%)	Melting point	External appearance; recrystallization solvent	Found (%) N	Found (%) s	Empirical formula	Calc. (%) N	Calc. (%) s	water	alcohol	acetone	benzene	carbon tetra-chloride	petroleum ether
													Solubility*			
m-C₆H₄	CH₃	CH₃	80.8	139—141°	Prisms; alcohol	9.36, 9.56	22.13, 22.30	$C_{10}H_{16}O_4N_2S_2$	9.63	21.92	−	+	+	+	‖	‖
m-C₆H₄	C₂H₅	C₂H₅	91.5	108—109	Prisms; alcohol	7.58, 7.63	18.48, 18.51	$C_{14}H_{24}O_4N_2S_2$	8.05	18.39	+	+	++	++	++	‖
n-C₆H₄	CH₃	CH₃	98.5	254—256 (with decom)	Scales; pyridine	9.44, 9.35	21.81, 22.00	$C_{10}H_{16}O_4N_2S_2$	9.63	21.92	‖	‖	‖	‖	‖	‖
n-C₆H₄	C₂H₅	C₂H₅	89.0	174—175	Prisms; methanol	7.98, 7.94	18.66, 18.68	$C_{14}H_{24}O_4N_2S_2$	8.05	18.39	‖	+	++	+	‖		
n-C₆H₄	H	CH₃	88.0	194—196	Concretions of prisms; methanol	10.51, 10.74	24.00, 24.12	$C_8H_{12}O_4N_2S_2$	10.60	24.24	+	−	++	−	‖	‖
n-C₆H₄	H	C₂H₅	70.2	154—155	Needles; benzene	9.42, 9.59	22.21, 22.04	$C_{10}H_{16}O_4N_2S_2$	9.63	21.92	−	++	++	++	‖	‖
m-SO₂(C₆H₄)₂	CH₃	CH₃	69.0	174—176	Platelets; alcohol	6.70, 6.78	22.40, 22.64	$C_{16}H_{20}O_6N_2S_3$	6.50	22.22	‖	+	+	−	‖	‖
m-SO₂(C₆H₄)₂	C₂H₅	C₂H₅	84.0	108—109	Prisms; methanol	5.78, 5.81	19.92, 19.80	$C_{20}H_{28}O_6N_2S_3$	5.74	19.67	+	++	++	++	+	+

*All the substances were insoluble in boiling ether.

TABLE 3

Chlorides of Phosphorus-Containing Derivatives of m- and p-Benzenedisulfonic Acids

Formula of substance	Yield (in %)	Melting point	External appearance; recrystallization solvent	Equivalent found after hydrolysis	Empirical formula	Calculated equivalent after hydrolysis	Solubility					
							acetone	benzene	carbon tetra-chloride	petro-leum ether	ether	dioxane
m-$C_6H_4(SO_2N=PCl_3)_2$	100.0	101—104°	Needles; benzene + petroleum ether	9.85, 9.70	$C_6H_4O_4N_2S_2P_2Cl_6$	10.00	+	−	−	−	=	+
p-$C_6H_4(SO_2N=PCl_3)_2$	100.0	153—157	Needles; benzene	9.90, 10.04	$C_6H_4O_4N_2S_2P_2Cl_6$	10.00	+	=	=	=	=	+
m-$C_6H_4(SO_2NHPOCl_2)_2$	58.5	152—154 (with de-comp.)	Fine crystals	8.05, 7.95	$C_6H_6O_6N_2S_2P_2Cl_4$	8.00	++	−	−	+	++	++
p-$C_6H_4(SO_2NHPOCl_2)_2$	81.0	152—154 (with de-comp.)	Fine crystals	7.80, 7.85	$C_6H_6O_6N_2S_2P_2Cl_4$	8.00	++	=	=	=	=	++

TABLE 4

Bistrialkoxy- and Bistriphenoxyphosphazosulfonophenylenes of the Type $C_6H_4(SO_2N = P(OR)_3)_2$

Position of substituents in C_6H_4	R	Yield (in %)	Melting point	External form; recrys-tallization solvent	N found (%)	Empirical formula	N calcu-lated (%)	Solubility						
								water	alcohol	acetone	benzene	carbon tetra-chloride	petro-leum ether	ether
m	CH_3	97.0	96— 98°	Concretions of prisms; water or alcohol	5.77, 5.73	$C_{12}H_{22}O_{10}N_2S_2P_2$	5.84	+	++	++	+	=	=	=
p	CH_3	71.4	117—119	Needles; methanol	5.89, 5.93	$C_{12}H_{22}O_{10}N_2S_2P_2$	5.84	=	−	+	+	=	=	=
m	C_2H_5	21.2	83—85	Needles; 25% alcohol	4.74, 4.90	$C_{18}H_{34}O_{10}N_2S_2P_2$	4.97	+	++	++	+	++	+	−
p	C_2H_5	25.6	101—102	Needles; 25% methanol	4.99, 4.84	$C_{18}H_{34}O_{10}N_2S_2P_2$	4.97	−	++	++	++	+	+	++
m	C_6H_5	72.0	100—102	Needles; CCl_4	3.38, 3.40	$C_{48}H_{34}O_{10}N_2S_2P_2$	3.29	−	++	++	++	+	=	=
p	C_6H_5	37.6	132—133	Needles; methanol	3.38, 3.44	$C_{42}H_{34}O_{10}N_2S_2P_2$	3.29	−	+	++	+	−	=	=

TABLE 5

Tetraesters of m- and p-Phenylenebissulfonamidophosphoric Acids of the Type $C_6H_4(SO_2NHPO(OR)_2)_2$

Position of substituents in C_6H_4	R	Yield (%)	Melting point	External appearance; recrystallization solvent	Found		Calc.* N (%)	Empirical formula	Solubility**			
					N (%)	equiv.			water	alco.	acet-one	benzene
p	CH_3	84.0	206—207°	Prisms; water or alcohol	6.31, 6.49	1.99	6.21	$C_{10}H_{18}O_{10}N_2S_2P_2$	+	+	–	‖
m	C_2H_5	39.4	152—153	Needles; water	5.69, 5.71	1.95	5.52	$C_{14}H_{26}O_{10}N_2S_2P_2$	+	+	++	–
p	C_2H_5	63.2	198—200	Prisms; alcohol	5.73, 5.90	2.04	5.52	$C_{14}H_{26}O_{10}N_2S_2P_2$	+	+++	++	‖
m	C_6H_5	73.6	205—207	Prisms; methanol	4.17, 4.31	2.06	4.00	$C_{30}H_{30}O_{10}N_2S_2P_2$	–	+	++	–
p	C_6H_5	67.5	225—228	Prisms; alcohol	4.04, 4.15	2.08	4.00	$C_{30}H_{30}O_{10}N_2S_2P_2$	–	+	+	–

*For all the substances, the calculated equivalent equalled 2.

**All the substances were insoluble in boiling carbon tetrachloride, ether, and petroleum ether.

have been studied quite thoroughly [5]. The phosphazo reaction has not been used up to the present time for diamides of disulfonic acids and bisphosphazo compounds derived from disulfonic acids were unknown up to now. Bisphosphazo compounds derived from sulfuric acid [6], urea [7], and isophthalic acid [8] have been described.

Experiment showed that the phosphazo reaction proceeded quantitatively for diamides of disulfonic acids with the formation of bistrichlorophosphazosulfonophenylenes, but at a considerably higher temperature (120-160°) than for amides of the simplest aromatic monosulfonic acids [5] and under approximately the same conditions as for amides of nitrophenylsulfonic acids [9]. The reaction proceeds by the scheme:

$$C_6H_5(SO_2NH_2)_2 + PCl_5 \longrightarrow$$

$$\longrightarrow 4HCl + C_6H_4(SO_2N{=}PCl_3)_2$$

m- and p-Bistrichlorophosphazosulfonophenylenes were colorless, crystalline substances. They were rapidly hydrolyzed by atmospheric moisture or by the action of water. Both bistrichlorophosphazosulfonophenylenes required 10 equiv. in titration to phenolphthalein. The properties of the bistrichlorophosphazosulfonophenylenes are presented in Table 3.

Like trichlorophosphazosulfonaryls, bistrichlorophosphazosulfonophenylenes reacted with formic acid [10]. This yielded the tetraacid chlorides of the corresponding phenylenebissulfonamidophosphoric acids by the scheme:

$$C_6H_5(SO_2N{=}PCl_3)_2 + 2HCOOH \longrightarrow$$

$$\longrightarrow 2CO + 2HCl + C_6H_4(SO_2NHPOCl_2)_2$$

The reaction occurred under much more drastic conditions than for trichlorophosphazosulfonaryls. In the case of the meta-derivative, the reaction occurred in boiling benzene over a period of 3 hours, while in the case of the para-derivative, the reaction was best carried out in boiling chlorobenzene, since p-bistrichlorophosphazosulfonophenylene was difficultly soluble in boiling benzene.

The tetraacid chlorides of m- and p-phenylenebissulfonamidophosphoric acids were colorless, crystalline substances; they were hydrolyzed by water and atmospheric moisture, but with considerably more difficulty than the corresponding

bistrichlorophosphazo compounds. Both the tetraacid chlorides required 8 equiv. in titration to phenolphthalein. Their melting points, solubilities, and yields are given in Table 3.

The action of sodium alcoholates or arylates on trichlorophosphazoaryls yielded trialkoxyphosphazosulfones and triaroxyphosphazosulfones [11]. Similarly, the action of sodium alcoholates and phenolates on bistrichloro-phosphazosulfonophenylenes yielded the corresponding bistrialkoxy- and bistriphenoxyphosphazosulfonophenylenes by the scheme:

$$C_6H_4(SO_2N\!\!=\!\!PCl_3)_2 + 6NaOR \longrightarrow$$
$$6NaCl + C_6H_4[SO_2N\!\!=\!\!P(OR)_3]_2$$
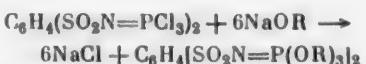
We thus obtained bistrimethoxy-, bistriethoxy- and bistriphenoxyphosphazosulfono-m- and p-phenylenes, which were colorless crystalline substances of a neutral character, quite stable during storage in air, unchanged by the action of water at room temperature, but readily hydrolyzed by boiling with water or aqueous alcohol to form tetraesters of the corresponding phenylenebissulfonamidophosphoric acids. The yields and properties of the bistrialkoxy- and bistriphenoxyphosphazosulfonophenylenes are presented in Table 4.

The action of excess methanol or ethanol, or 8 moles of sodium alcoholates or phenolates on m- and p-bistrichlorophosphazosulfonophenylenes gave good yields of the symmetrical tetraesters of m- and p-phenylene-bissulfonamidophosphoric acids (cf. [11]) by the scheme:

$$C_6H_4(SO_2N\!\!=\!\!PCl_3)_2 + 8NaOR \longrightarrow 6NaCl + 2R_2O + C_6H_4[SO_2NNaPO(OR)_2]_2$$

$$C_6H_4(SO_2N\!\!=\!\!PCl_3)_2 + 6HOR \longrightarrow 4HCl + 2RCl + C_6H_4[SO_2NHPO(OR)_2]_2$$
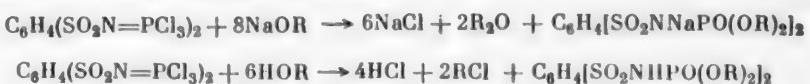
In their properties, the tetramethyl and tetraethyl esters of m- and p-phenylenebissulfonamidophosphoric acids were reminiscent of diesters of arylamidophosphoric acids. They were quite strong dibasic acids, which readily dissolved in aqueous solutions of caustic and carbonate alkalis, required 2 equiv. in titration to phenol-phthalein, and gave readily water-soluble sodium salts (with the exception of the difficultly soluble sodium salt of the tetraphenyl ester of p-phenylenebissulfonamidophosphoric acid). The yields and properties of the esters are presented in Table 5.

EXPERIMENTAL

<u>m-Benzenedisulfonyl chloride</u> was obtained by the action of a mixture of oleum and chlorosulfonic acid on benzene, at first with cooling, and then at the boiling point of chlorosulfonic acid. For each mole of benzene, 2 moles of sulfur trioxide in the form of 65% oleum and 8 moles of chlorosulfonic acid were used. Hydrogen chloride was not liberated during the reaction. The cooled dark brown liquid was poured onto ice and the mixture of diacid chlorides of m-benzenedisulfonic acid and m,m'-diphenyl sulfone disulfonic acid was sucked off and treated with CCl_4, in which the diacid chloride of m,m'-diphenyl sulfone disulfonic acid was very sparingly sol-uble and the diacid chloride of m-benzenedisulfonic acid dissolved very readily. The total yield of the chlorides was about 70%. This method is considerably more convenient than those described in the literature [12].

There is no description in the literature of a simple and convenient method of preparing p-benzenedisul-fonic acid. We therefore used separate stages of different syntheses described in the literature. As the starting material we chose the comparatively cheap and readily available sulfanilamide, which was converted into a mixture of the sodium salt of p-thiophenolsulfonamide and p,p'-diphenyl disulfide disulfonamide by a method analogous to that for the preparation of o,o'-diphenyl disulfide dicarboxylic acid from anthranilic acid [13].

The mixture of the sodium salt of p-thiophenolsulfonamide and p,p'-diphenyl disulfide disulfonamide was oxidized with nitric acid by a method analogous to that for the oxidation of p,p'-diphenyl disulfide disulfonamide to p-benzenedisulfonic acid, proposed by Aiello and Pappalardo [14]. However, the abstract of this work (we were unable to acquaint ourselves with the original work) did not describe the oxidation details with sufficient accur-acy and, therefore, we were obliged to choose them. The p-benzenedisulfonic acid and its monosodium salt, ob-tained after the oxidation, were converted to the disodium salt, which was converted to p-benzenedisulfonyl chloride by treatment with phosphorus pentachloride [15]. The yield of p-benzenedisulfonyl chloride, calculated on sulfanilamide, was 65-70%, which can be considered satisfactory. However, due to the many stages and its laboriousness, the method cannot be considered convenient.

When this work was almost complete, an article was published by Meerwein et al. [16], in which a description was given of a comparatively simple method of converting aromatic amines into sulfonyl chlorides by the scheme:

$$ArNH_2 \xrightarrow[+HCl]{+NaNO_2} ArN_2Cl \xrightarrow[+CuCl+CH_3COOH]{+SO_2} ArSO_2Cl$$
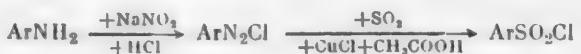
Treatment of sulfanilic acid by Meerwein's method yielded the readily water-soluble monoacid chloride of p-benzenedisulfonic acid, which could not be isolated as such. Therefore, the p-benzenedisulfonic acid had to be isolated as the disodium salt, which involved great difficulties due to the large volumes of the reaction mixtures.

It would be possible to obtain p-benzenedisulfonyl chloride from p-phenylenediamine by Meerwein's method. However, this procedure is hardly of practical interest since p-phenylenediamine is dear and difficultly accessible. It was therefore decided to use Meerwein's method for the synthesis of the previously unknown mono-amide-monochloride of p-benzenedisulfonic acid from the cheap and readily available sulfanilamide. It was found that the monoamide-monochloride of p-benzenedisulfonic acid was hydrolyzed by water comparatively slowly and was very difficultly soluble in water and, therefore, it could be obtained directly from sulfanilamide in about 80% yield by the scheme:

$$p\text{-}NH_2SO_2C_6H_4NH_2 \xrightarrow[+HCl]{+NaNO_2} p\text{-}NH_2SO_2C_6H_4N_2Cl \xrightarrow[+CuCl+CH_3COOH]{+SO_2}$$
$$\longrightarrow p\text{-}NH_2SO_2C_6H_4SO_2Cl$$
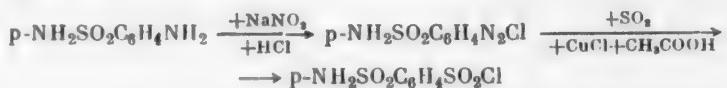
Apparently, at the present time, this is the least laborious and cheapest method of preparing a simple derivative of p-benzenedisulfonic acid, which can serve as the starting material for the preparation of free p-benzenedisulfonic acid, its dichloride, and many symmetrical and unsymmetrical derivatives.

Preparation of the monoamide-monochloride of p-benzenedisulfonic acid. To a suspension of 1 mole of sulfanilamide in 150 ml of concentrated HCl was slowly added a solution of 1 mole of $NaNO_2$ in 20 ml of water, so that the temperature of the reaction mixture did not rise above +10°. When all the sodium nitrite had been added, the solution was kept at the same temperature for about half an hour and then it was poured with vigorous stirring into a previously prepared solution of SO_2 in glacial acetic acid (300 g of SO_2 in 700 g of CH_3COOH). For each 0.1 mole of sulfanilamide it was necessary to take 200 g of the given solution and 1 g of CuCl as catalyst. When the solutions mixed, the evolution of nitrogen began and was complete in approximately 30 minutes. After this, about 1 liter of ice water was added to the reaction mixture. A colorless precipitate of the monoamide-monochloride of p-benzenedisulfonic acid formed immediately and was sucked off, washed with water (5 × 10 ml) and dried in vacuum. The yield was 19.7 g (78.3%); the m.p. was 153-156°, and the substance formed a fine, crystalline powder.

Found %: N 5.62, 5.64; S 24.45, 24.48. Equiv. after hydrolysis 2.02. $C_6H_6O_4NS_2Cl$.

Calculated %: N 5.49; S 25.0. Equiv. after hydrolysis 2.00.

The colorless crystalline substance reacted slowly with water at room temperature, but rapidly on heating; it was very readily soluble in methanol and ethanol (it reacted with them slowly), acetone, and ether, and was sparingly soluble in benzene, petroleum ether, and carbon tetrachloride.

The diamides of m- and p-benzenedisulfonic acids, and also of m,m'-diphenyl sulfone disulfonic acid were synthesized by methods described in the literature from the corresponding diacid chlorides and ammonia [3, 4, 17]. The diamide of p-benzenedisulfonic acid was also obtained by the action of ammonia on the monochloride-monoamide of p-benzenedisulfonic acid, which demonstrated the structure of the latter.

p-Benzenedisulfonamide from the monoamide-monochloride of p-benzenedisulfonic acid. 0.05 mole of the monoamide-monochloride of p-benzenedisulfonic acid was dissolved in 50 ml of methanol at 0° and 6.8 ml of a concentrated aqueous solution of ammonia added immediately. A mixture of diamide and ammonium chloride precipitated and was collected by filtration and washed with water (4 × 5 ml) to remove the ammonium chloride. The yield was 84.0% of prisms (from 50% alcohol) with m.p. 286-288°, undepressed by admixture with authentic p-benzenedisulfonamide. In the action of an aqueous solution of ammonia or gaseous ammonia on a suspension of the monoamide-monochloride of p-benzenedisulfonic acid in C_6H_6 or CCl_4, the yields were appreciably lower.

Dimethyl ester of m-benzenedisulfonic acid. 0.06 g-at. of metallic sodium was dissolved in 25 ml of CH_3OH, the solution evaporated to a thick sirup and 0.03 mole of m-benzenedisulfonyl chloride in 50 ml of benzene added. The reaction mixture gave off heat and a precipitate of NaCl formed immediately. After 1.5 hours, the solution was evaporated to dryness in vacuum on a water bath, then 100 ml of benzene added, and the NaCl removed by filtration. Removal of the benzene in vacuum left dimethyl m-benzenedisulfonate.

The rest of the esters (Table 1) were obtained similarly, but in the preparation of esters of diphenyl sulfone disulfonic acid, the reaction mixture was boiled for 3 hours under reflux.

The methylation of 2-methylbenzthiazole with methyl m- and p-benzenedisulfonates was carried out under the conditions described by A. I. Kiprianov and A. I. Tolmachev [2]. For each experiment, 5.0 ml of a 0.08 M solution of the components in toluene was used and the mixture was heated in a thermostat at 90° for 3, 4, and 5 hours. The greatest deviations from the average values of the constants presented in the general section, for separate experiments, was about $1 \cdot 10^{-5}$.

Tetramethyldiamides of disulfonic acids (Table 1). To a solution of 0.01 mole of the disulfonyl dichloride in 50 ml of benzene was added 9 ml of a 33% aqueous solution of dimethylamine. A thick, white precipitate formed immediately, and, after an hour, this was collected by filtration and washed with water (3 × 10 ml).

Tetraethyldiamide of m-benzenedisulfonic acid (Table 2). To a solution of 0.01 mole of m-benzenedisulfonyl chloride in 25 ml of dry benzene was slowly added a solution of 0.05 mole of diethylamine in 12 ml of C_6H_6. The solution evolved heat, and after several minutes a precipitate formed, which consisted of diethylamine hydrochloride and an insignificant amount of the tetraethyldiamide of m-benzenedisulfonic acid. On the following day, the precipitate was filtered and washed with water (4 × 3 ml). On the filter remained 0.52 g of the tetraethyldiamide of m-benzenedisulfonic acid. The benzene solution was evaporated to dryness in vacuum on a water bath to leave 2.77 g of the tetraethyldiamide of m-benzenedisulfonic acid.

The tetraethyldiamide of p-benzenedisulfonic acid was obtained, as in the previous experiment, but it was difficultly soluble in benzene and, therefore, precipitated together with diethylamine hydrochloride. The mixture of products was collected by filtration and treated with water (4 × 3 ml) to remove the diethylamine hydrochloride.

The tetraethyldiamide of m,m'-diphenyl sulfone disulfonic acid was also obtained similarly to the tetraethyldiamide of m-benzenedisulfonic acid.

Unsymmetrical dimethyldiamide of p-benzenedisulfonic acid (Table 2). 0.06 mole of the monoamide-monochloride of p-benzenedisulfonic acid was dissolved in 75 ml of methyl alcohol, and 0.14 mole of dimethylamine was added to the solution immediately in the form of a saturated aqueous solution. The reaction mixture gave off heat and a precipitate began to form immediately. After an hour, it was collected by filtration and washed with water (2 × 5 ml) and methyl alcohol (2 × 5 ml).

Unsymmetrical diethyldiamide of p-benzenedisulfonic acid. 0.01 mole of the monoamide-monochloride of p-benzenedisulfonic acid was dissolved in 25 ml of CH_3OH and 0.025 mole of diethylamine in 10 ml of C_6H_6 was added immediately to the solution. The reaction mixture evolved heat but no precipitate formed. On the following day, the solution was evaporated in vacuum on a water bath. The residual oil was a mixture of the unsymmetrical diethyldiamide of p-benzenedisulfonic acid and diethylamine hydrochloride. The diethyldiamide was insoluble in water and, therefore, 10 ml of water was added to the mixture, when the diethylamine hydrochloride dissolved, and the diethyldiamide was collected by filtration, washed with water (2 × 5 ml) and dried.

m-Bistrichlorophosphazosulfonophenylene (Table 3). Into a round-bottomed flask with an air condenser was placed 0.02 mole of carefully dried and ground m-benzenedisulfonamide and 0.048 mole of PCl_5. The flask was immersed in an oil bath. At 120°, the evolution of HCl began and was complete after about an hour. During this time, the reaction mixture liquified completely and appeared as a quite mobile yellowish liquid. The excess PCl_5 was removed in vacuum at 120°. After several hours, the m-bistrichlorophosphazosulfonophenylene crystallized.

p-Bistrichlorophosphazosulfonophenylene was obtained as in the previous experiment, but the reaction was carried out at 160-170° and therefore a slightly larger excess of PCl_5 was used (0.056 mole of PCl_5 to 0.02 mole of p-benzenedisulfonamide). The p-bistrichlorophosphazosulfonophenylene crystallized immediately after the flask was removed from the bath.

Tetraacid chloride of m-phenylenebissulfonamidophosphoric acid. To a solution of 0.01 mole of m-bistrichlorophosphazosulfonophenylene in 75 ml of benzene was added 0.02 mole of anhydrous formic acid, and the reaction mixture boiled for 3 hours. After 15-20 minutes, a precipitate of the tetraacid chloride of m-phenylenebissulfonamidophosphoric acid began to form. After the heating, the product was collected by filtration and dried in vacuum.

The tetraacid chloride of p-phenylenebissulfonamidophosphoric acid was obtained as in the previous experiment, but the reaction was carried out in chlorobenzene, since p-bistrichlorophosphazosulfonophenylene is difficultly soluble in benzene (1 g in 100 g of C_6H_6).

m-Bistrialkoxyphosphazosulfonophenylene (Table 4). 0.12 g-at. of sodium was dissolved in 30 ml of methanol or ethanol. The solution of sodium alcoholate was placed in a flask, fitted with a stirrer, a thermometer, and a dropping funnel, and cooled to —10°. A solution of 0.02 mole of the appropriate bistrichlorophosphazosulfonophenylene in 150 ml of dioxane was then added gradually, so that the temperature of the reaction mixture did not rise above 0°. When the reaction was complete (neutral reaction to Congo), the NaCl was removed by filtration and the solvent removed in vacuum. To the residue was added 10-15 ml of ice water, and the insoluble bistrialkoxyphosphazosulfonophenylene collected and dried.

m-Bistriphenoxyphosphazosulfonophenylene. 0.005 mole of m-bistrichlorophosphazosulfonophenylene was dissolved in 50 ml of dioxane, and to the solution was added 0.03 mole of dry, carefully ground sodium phenolate. The mixture heated up to 40-50°. After 10-15 minutes, the precipitate of phenolate was replaced by a precipitate of NaCl. After a further 15 minutes, the NaCl was removed by filtration, the solution evaporated to dryness in vacuum, and 25 ml of ice water added to the residue. The water-insoluble m-bistriphenoxyphosphazosulfonophenylene was sucked off and dried.

p-Bistriphenoxyphosphazosulfonophenylene was obtained similarly to the previous product, but chlorobenzene was used as the solvent.

Tetramethyl ester of p-phenylenebissulfonamidophosphoric acid (Table 5). With cooling in ice, 0.005 mole of p-bistrichlorophosphazosulfonophenylene was gradually added to 25 ml of methanol. After 15-20 minutes, the whole of the phosphazo compound had dissolved and the reaction mixture was a clear, slightly yellowish solution. It was left for 2-3 days at room temperature. During this time, a precipitate of the tetramethyl ester of p-phenylenebissulfonamidophosphoric acid formed, and this was collected by filtration, washed with methanol (2 × 3 ml) and dried.

Tetraethyl ester of m-phenylenebissulfonamidophosphoric acid. To a solution of 0.04 g-at. of sodium in 25 ml of ethanol was added 0.005 mole of m-bistrichlorophosphazosulfonophenylene, dissolved in 100 ml of dioxane. A precipitate of NaCl formed immediately. After an hour, it was removed by filtration, and the solution evaporated to dryness. The residue was the sodium salt of the tetraethyl ester of m-phenylenebissulfonamidophosphoric acid, which was dissolved in a small amount of water. The solution was filtered and acidified with HCl. The free tetraethyl ester of m-phenylenebissulfonamidophosphoric acid precipitated and was collected, washed with water, and dried.

Tetraethyl ester of p-phenylenebissulfonamidophosphoric acid was obtained in the same way as the tetramethyl ester of p-phenylenebissulfonamidophosphoric acid.

Tetraphenyl ester of m-phenylenebissulfonamidophosphoric acid. To a solution of 0.002 mole of m-bistrichlorophosphazosulfonophenylene in 50 ml of benzene was added 0.017 mole of dry, carefully ground sodium phenolate. The reaction mixture was boiled for 8 hours and then the NaCl was removed and the solution evaporated to dryness. The residue was the sodium salt of the tetraphenyl ester of m-phenylenebissulfonamidophosphoric acid. It was dissolved in 50 ml of water, the solution filtered and acidified with hydrochloric acid. The free tetraphenyl ester of m-phenylenebissulfonamidophosphoric acid precipitated in the form of a thick, viscous mass, which rapidly crystallized.

Tetraphenyl ester of p-phenylenebissulfonamidophosphoric acid. To a solution of 0.005 mole of p-bistrichlorophosphazosulfonophenylene in 70 ml of dioxane was added 0.04 mole of dry, carefully ground sodium phenolate. The reaction mixture evolved heat strongly. It was then boiled for 2 hours. During this time, a precipitate formed consisting of NaCl and the sodium salt of the tetraphenyl ester, which had a low solubility in water. The precipitate was therefore collected and treated with 50 ml of water to remove NaCl. The residue

was the sodium salt of the tetraphenyl ester of p-phenylenebissulfonamidophosphoric acid. The yield was 2.5 g (67.5%). To prepare the free tetraester, the sodium salt was dissolved in hot water and the solution acidified with HCl. The free tetraester precipitated immediately and was collected, washed, and dried.

SUMMARY

1. The methyl and ethyl esters of m- and p-benzenedisulfonic acids and m,m'-diphenyl sulfone disulfonic acid were prepared, and it was shown that the methyl esters of m- and p-benzenedisulfonic acids were intermediate between methyl arylsulfonates and methyl nitroarylsulfonates in their alkylating capacity.

2. The monoamide-monochloride of p-benzenedisulfonic acid and a series of N-alkylated amides of m- and p-benzenedisulfonic acid were prepared.

3. The phosphazo reaction was carried out on diamides of m- and p-benzenedisulfonic acids, and we prepared m- and p-bistrichlorophosphazosulfonophenylenes, tetraacid chlorides of m- and p-phenylenebissulfon-amidophosphoric acids, m- and p-bistrialkoxy- and bistriphenoxyphosphazosulfonophenylenes and tetraesters of m- and p-phenylenebissulfonamidophosphoric acids, and described their properties.

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REACTION OF PHOSPHORUS PENTACHLORIDE WITH
N-CHLORO DERIVATIVES OF ARYLSULFONAMIDES

E. S. Levchenko and A. V. Kirsanov

Institute of Organic Chemistry, Academy of Sciences, UkrSSR

Original article submitted May 27, 1958

Up to the present time, there have been two methods for preparing trichlorophosphazo compounds, namely, the phosphazo reaction, i.e., the interaction of phosphorus pentachloride with acid amides [1], and the action of phosphorus trichloride on the sodium salts of chloroamides of sulfonic acids [2], which proceeds by the scheme:

$$ArSO_2NNaCl + PCl_3 \longrightarrow NaCl + ArSO_2N{=}PCl_3.$$

It was previously proposed [2] that the main motive force of this reaction was the tendency of the trivalent phosphorus atom to change into the more favorable, formally pentavalent state. However, it was found that not only phosphorus trichloride, but also phosphorus pentachloride, reacted vigorously with both the sodium salts of N-chloroamides of sulfonic acids and with N,N-dichloroamides of sulfonic acids to form trichlorophosphazo compounds and free chlorine by the schemes:

$$ArSO_2NNaCl + PCl_5 \longrightarrow NaCl + Cl_2 + ArSO_2N{=}PCl_3,$$
$$ArSO_2NCl_2 + PCl_5 \longrightarrow 2Cl_2 + ArSO_2N{=}PCl_3.$$
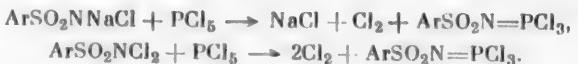
The reaction proceeds readily and, in most cases, with almost quantitative yields and the formation of very pure trichlorophosphazo compounds. Apparently, the formation of phosphazo compounds is extremely "favored," but, in most reactions, this "favoring" is masked by possibility of conversion of the $P{=}N$ bond into the even more "favored" $P{=}O$ bond.

Without solvent, the reaction of phosphorus pentachloride with sodium salts of N-chlorosulfonamides proceeds with such vigor that the reaction products are completely carbonized. In carbon tetrachloride solution the reaction begins at room temperature, is accompanied by the liberation of heat, and is rapidly complete. In carbon tetrachloride solution at room temperature, N,N-dichloroamides of sulfonic acids react slowly with phosphorus pentachloride, but very rapidly on heating.

EXPERIMENTAL

Reaction of Phosphorus Pentachloride with Sodium Salts of N-Chloroarylsulfonamides

To a suspension of 0.03 mole of the sodium salt of the N-chloroarylsulfonamide in 50 ml of carbon tetrachloride was added 0.03 mole of phosphorus pentachloride in small portions. The mixture evolved heat and, as the phosphorus pentachloride was added, the sodium chloroamide gradually passed into solution, which acquired a yellow color and gave off chlorine. After 2-3 hours, the sodium chloride was removed by filtration and the CCl_4 distilled from the filtrate in vacuum on a water bath. The residue was a clear, colorless oil, which crystallized completely on cooling. Yields: phenyl trichlorophosphazosulfone 88%, m.p. 50-53° [1], p-tolyl trichlorophosphazosulfone 94%, m.p. 106-108° [1], p-chlorophenyl trichlorophosphazosulfone about 100%, m.p. 69-71° [3] and m-nitrophenyl trichlorophosphazosulfone about 100%, m.p. 78-80° [4]. The products were identified by mixed melting points.

Reaction of Phosphorus Pentachloride with N,N-Dichloroarylsulfonamides

To a solution of 0.03 mole of dichloroarylsulfonamide in 50 ml of carbon tetrachloride was added 0.03 mole of phosphorus pentachloride, and the mixture left at room temperature for a day. The phosphorus pentachloride passed into the solution, which acquired a yellow color and gave off chlorine. (The reaction proceeded much more rapidly on heating.) The carbon tetrachloride was removed in vacuum on a water bath. The residue was aryl trichlorophosphazosulfones in the form of colorless oily liquids, which rapidly crystallized completely. Yields: phenyl trichlorophosphazosulfone 98%, m.p. 50-53° [1], p-chlorophenyl trichlorophosphazosulfone 94%, m.p. 69 to 71° [3], and m-nitrophenyl trichlorophosphazosulfone about 100%, m.p. 79-82° [4]. The products were identified by mixed melting points.

SUMMARY

The reaction of phosphorus pentachloride with sodium salts of N-chlorosulfonamides and with N,N-dichlorosulfonamides proceeds almost quantitatively with the formation of aryl trichlorophosphazosulfones and free chlorine.

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C-PHOSPHINYL-P,P-DIAROXYISOPHOSPHAZOAROYLS

G. I. Derkach and A. V. Kirsanov

Institute of Organic Chemistry, Academy of Sciences, UkrSSR

Original article submitted May 27, 1958

In their structure, C-chloro-P,P-diaroxyisophosphazoacyls of the type $ArCCl{=}NPO(OAr')_2$ are acid chlorides of imino carboxylic acids, in which the hydrogen atom on the nitrogen has been replaced by an esterified phosphoric acid residue [1]. Therefore, C-chloro-P,P-diaroxyisophosphazoacyls must possess the chemical properties of acid chlorides of carboxylic acids. Actually, with water they give diaryl esters of acylamidophosphoric acids [1], with sodium alcoholates and arylates they give the corresponding esters [2], and they react readily with ammonia and amines, i.e., they possess clearly expressed acylating properties and, consequently, are analogous to acid chlorides of carboxylic acids. It seemed interesting to determine whether this analogy extended to the A. E. Arbuzov reaction, i.e., whether C-chloro-P,P-diaroxyisophosphazoacyls would react with esters of phosphorous acid analogously to acid chlorides of carboxylic acids. As has been found by M. I. Kabachnik and P. A. Rossiiskaya [3], the latter react with esters of phosphorous acid to give esters of α-ketophosphinic (carbacylphosphinic) acids.

Experiments showed that C-chloro-P,P-diaroxyisophosphazoacyls underwent the A. E. Arbuzov reaction very readily, even at $-15°$, with the evolution of a large amount of heat and the formation of the corresponding C-phosphinyl-P,P-diaroxyisophosphazoaroyls* by the scheme:

$$ArCCl{=}NPO(OAr')_2 + P(OAlk)RR' \longrightarrow AlkCl + \underset{\overset{|}{OPRR'}}{ArC}{=}NPO(OAr')_2. \qquad (I)$$

The reaction proceeds equally readily for triethyl phosphite and the methyl and ethyl esters of phenylphosphinous and diphenylphosphinous acids. The alkyl halide liberated during the reaction also reacts with trialkyl phosphites to form the esters of the corresponding phosphinic acids. Therefore, in certain cases, the reaction is best carried out in vacuum so that the alkyl halide liberated may be removed as rapidly as possible.

Of the ten C-phosphinyl-P,P-diaroxyisophosphazoaroyls (I) obtained, two were colorless crystalline substances and seven were thick liquids or glassy substances. They were purified by 3-4 fractional reprecipitations with petroleum ether from a solution in benzene or acetone. The yields of the "crude" substances (I) were almost quantitative, and after recrystallization or reprecipitation, they were about 50%. We were unable to obtain the liquids (I) completely colorless. They all had a characteristic weak smell of yeast or baked bread. When stored at room temperature, the crystalline substances (I) were converted, first into thick liquids and then into glassy solid products after two to three weeks, and the liquids gradually thickened.

The analytical data, external appearance, solubilities, and melting points of the substances (I) are presented in the table.

When shaken with 90% alcohol at 20° for 4-6 hours, (I) were quantitatively hydrolyzed with the formation of diesters of acylamidophosphoric acids, and the corresponding acid esters of phosphorous or phosphinous acids or free diphenylphosphinous acid by the scheme:

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*Phosphinyl is the radical with the structure H_2PO-.

OPRR'

C-Phosphinyl-P,P-diaroxylsophosphazoaroyls of the Type $ArC=NPO(OAr')_2$

Sub-stance	Ar*	R	R'	Alk**	External appearance; crystallization solvent, melting point	P found (%)	Empirical formula	P calculated (%)	Solubility*** alcohol	C.H.	CCl₄	ether	petroleum ether
(II)	C_6H_5	C_6H_5	OC_2H_5	C_2H_5	Platelets: CCl_4; 104—105°	12.06	$C_{27}H_{25}O_5NP_2$****	12.27	+	+	+	+	−
(III)	C_6H_5	C_6H_5	OCH_3	CH_3	Thick, viscous liquid	12.43	$C_{26}H_{23}O_5NP_2$	12.62	+	+	−	+	−
(IV)	C_6H_5	C_6H_5	C_6H_5	CH_3	Prisms; C_6H_6 + petroleum ether; 123-125°	11.60	$C_{31}H_{25}O_5NP_2$*****	11.53	+	++	−	+	−
(V)	C_6H_5	OC_2H_5	OC_2H_5	C_2H_5	Thick, viscous liquid	13.00	$C_{23}H_{25}O_6NP_2$	13.09	+	++	++	+	−
(VI)	$p-ClC_6H_4$	C_6H_5	OC_2H_5	C_2H_5	Glassy mass	11.70	$C_{27}H_{24}O_5NP_2Cl$	11.48	+	+	++	++	−
(VII)	$p-ClC_6H_4$	C_6H_5	OCH_3	CH_3	Thick, viscous liquid	12.00	$C_{26}H_{22}O_5NP_2Cl$	11.80	+	+	+	+	−
(VIII)	$p-ClC_6H_4$	C_6H_5	C_6H_5	CH_3	Thick, viscous liquid	10.67	$C_{31}H_{24}O_4NP_2Cl$	10.89	+	+	+	+	−
(IX)	$p-ClC_6H_4$	OC_2H_5	OC_2H_5	C_2H_5	Thick, viscous liquid	12.00	$C_{23}H_{24}O_6NP_2Cl$	12.21	++	++	+	+	−
(X)	C_6H_5	C_6H_5	OC_2H_5	C_2H_5	Glassy mass: 48-52°. (52°)	10.41	$C_{33}H_{29}O_5NP_2$******	10.66	+	+	+	+	−

* In (II)-(IX) Ar' = C_6H_5, in (X) Ar' = $\alpha-C_{10}H_7$.

** Alk determined the composition of the ester of phosphorous or phosphinous acid, RR'·POAlk, taken for the reaction and was eliminated as AlkCl during the reaction.

*** All (I) were insoluble in water and readily soluble in acetone at 20°. Symbols: − difficultly soluble on boiling, + readily soluble on boiling, ‡ readily soluble at 20°.

**** Found %: N 2.71. Calculated %: N 2.77.

***** Found %: N 2.60. Calculated %: N 2.60.

****** Found %: N 2.21. Calculated %: N 2.40.

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$$\text{ArC} = \text{NPO(OAr')}_2 \xrightarrow{+\text{H}_2\text{O}} \text{ArCONHPO(OAr')} + \text{HOPRR'}.$$
$$|$$
$$\text{OPRR'}$$

On boiling, hydrolysis occurred in 1 hour. In the presence of hydrochloric acid, the hydrolysis proceeded by the same scheme, but the diesters of acylamidophosphoric acids formed were hydrolyzed further to free aromatic acids. The diesters of acylamidophosphoric acids were identified by the melting point of a mixture with authentic substances and the amount of trivalent phosphorus derivative formed was determined by titration with iodine at pH 6 and equalled 90-100%.

In the hydrolysis of (IV) and (VIII) it was possible to isolate almost quantitative yields of diphenylphosphinous acid, which was identified by conversion to diphenylphosphinic acid by oxidation with iodine or perhydrol. Diphenylphosphinous acid was recently obtained by B. Hunt and B. Saunders by the action of phenylmagnesium bromide on diethyl phosphite [4]. We obtained diphenylphosphinous acid by a simpler method, namely, the hydrolysis of diphenylchlorophosphine in carbon tetrachloride solution. The diphenylphosphinous acid synthesized by this method was oxidized quantitatively by perhydrol or iodine to diphenylphosphinic acid as in the case of diphenylphosphinic acid obtained by hydrolysis of (IV) and (VIII).

When (I) was hydrolyzed in alkaline solution, benzaldehyde was not detected (cf. [3]).

If, in the preparation of (I), one of the starting components was dimethyl phenylphosphinite [preparation of substances (III) and (VII)] and the reaction was carried out at a higher temperature (about 130°) and for a longer time (about 3 hours), then, as a side product, we obtained 5-10% of triphenyltriazine or tri-p-chlorotriphenyltriazine, which were identified by the melting points and analysis for nitrogen. In the other cases, no triaryltriazine formation was observed, even if the reaction was carried out at even higher temperatures. Triaryltriazine formation did not occur either when pure (III) and (VII) were heated under the same conditions.

EXPERIMENTAL

C-Phenylethoxyphosphinyl-P,P-Diphenoxyisophosphazobenzoyl (II). To 0.02 mole of C-chloro-P,P-diphenoxyisophosphazobenzoyl, cooled to −15°, was added 0.02 mole of diethyl phenylphosphinite in one portion. The reaction mixture heated up quite strongly (to about +50°) and frothed (evolution of ethyl chloride). When the evolution of gas bubbles began to slow, the reaction mixture was heated for 40-50 minutes at 80-100°. During this time, about 95% of ethyl chloride was liberated and this was trapped and identified by the usual methods. For complete removal of the ethyl chloride, the brown liquid obtained was kept in vacuum for a few minutes, then 2-3 ml of ether and 2 ml of petroleum ether were added and the mixture left at room temperature. After 1-2 hours, the mixture was converted into a solid, crystalline mass, which was powdered, sucked off, washed with petroleum ether (2 × 3 ml) and dried. The yield of (II) was 51%.

C-Phenylmethoxyphosphinyl-P,P-diphenoxyisophosphazobenzoyl (III). 0.02 mole of C-chloro-P,P-diphenoxyisophosphazobenzoyl was placed in a Claisen flask, fitted with a thermometer and a dropping funnel, cooled to −15° and dimethyl phenylphosphinite slowly added dropwise in vacuum (about 10 mm). After the addition, the mixture was heated on an oil bath at 50-60° for 1 hour. The reaction product was a thick yellow oil, obtained in 100% yield. When the reaction was carried out without vacuum, a considerable amount of the methyl ester of methylphenylphosphinic acid was formed. Heating the reaction mixture to 100-130° for 1-3 hours formed about 5% of triphenyltriazine with m.p. 228-230°, which corresponds with literature data [5].

C-Diphenylphosphinyl-P,P-diphenoxyisophosphazobenzoyl (IV) and C-Diethoxyphosphinyl-P,P-diphenoxyisophosphazobenzoyl (V) were also obtained similarly to (II) and substances (VI)-(X), similarly to (III). If the reaction was carried out at 100-130° for 3 hours in the preparation of (VII), then about 10% of tri-p-chlorotriphenyltriazine was formed; m.p. 334°, which agrees with literature data [5].

Diphenylphosphinous Acid. With vigorous stirring in an atmosphere of hydrogen, 0.02 mole of water was slowly added dropwise to a solution of 0.02 mole of diphenylchlorophosphine in 30 ml of CCl$_4$, and after all the water had been added, stirring was continued at room temperature for 6 hours. The carbon tetrachloride was removed in vacuum and the residue was diphenylphosphinous acid as a thick, oily liquid, which crystallized completely after 10-12 hours. The yield was 96% and after recrystallization from ether, the product had m.p. 53-56°, which corresponds with literature data [4]. Under the action of iodine in an aqueous solution at pH 6 or under, the action of perhydrol, diphenylphosphinous acid was quantitatively converted into diphenylphosphinic acid.

Hydrolysis of C-Phosphinyl-P,P-Diaroxyisophosphazoaroyls was carried out for substances (IV), (V), (VII) and (IX). A mixture of 0.01 mole of substance, 50-60 ml of alcohol and 5 ml of water was shaken for 6 hours at room temperature or boiled for a period of 1 hour. The alcohol was removed in vacuum to a volume of 20 ml and the solution was left to stand for a day. The precipitated crystals of the diester of acylamidophosphoric acid were collected by filtration and recrystallized. The yields were from 50 to 75%. The products were identified by mixed melting points. The mother liquors were evaporated in vacuum and the residue [for substances (IV) and (VIII) this was diphenylphosphinous acid in almost quantitative yield] was dissolved in buffer solution and titrated with iodine at pH 6. The consumption of iodine for substances (IV) and (VIII) was almost theoretical, and about 90% for substances (V) and (IX). The yield of diphenylphosphinic acid [from substances (IV) and (VIII) after oxidation] was almost quantitative.

SUMMARY

C-Chloro-P,P-diaroxyisophosphazoaroyls readily undergo the A. E. Arbuzov reaction with esters of phosphorous, phenylphosphinous and diphenylphosphinous acids to form the corresponding C-phosphinyl-P,P-diaroxy-isophosphazoaroyls.

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* Original Russian pagination. See C.B. Translation.

ADDITION OF DIALKYLPHOSPHOROUS ACIDS TO ALKYL ISOTHIOCYANATES

K. A. Petrov and A. A. Neimysheva
Original article submitted March 20, 1958

It is known that dialkyl phosphites readily add to many substances containing multiple carbon — carbon, carbon — nitrogen and carbon — oxygen bonds to form various organophosphorus compounds. In a series of cases, this method of synthesizing organophosphorus compounds, which was first proposed by Pudovik [1], is preferable to the Michaelis-Becker and Arbuzov reactions, and may be applied successfully in synthetic work. In a study of this reaction, it was also shown that, as a result of mixing alkyl isothiocyanates with phosphites, there was evolution of heat by the reaction mixture, but in contrast to the reaction with isocyanates [2-5], the corresponding addition products could not be isolated. When the reaction mixture was vacuum distilled, the reaction products decomposed with the formation of low-boiling substances [3].

In this work, it was shown that dialkyl phosphites add to alkyl isothiocyanates with the formation of esters of alkylamidophosphonothioformic acid

$$(RO)_2POH + RNCS \xrightarrow{RONa} \begin{array}{c} RO \\ RO \end{array} P - C \begin{array}{c} S \\ NHR. \end{array}$$

The reaction proceeds in the presence of sodium alcoholate with the evolution of heat, and is completed by heating. The duration of heating and reaction temperature have a marked effect on the yield of final product. The alkylamidophosphonothioformic ester is obtained in good yield by heating at 110° for 2-2.5 hours. With any change in the reaction temperature and the heating time, a sharp fall in ester yield is observed. It should be noted that if the reaction mixture is vacuum distilled immediately after the end of heating, after removal of the low-boiling fractions, the reaction product decomposes, in most cases. The esters of alkylamidophosphonothioformic acid may be distilled only after the reaction mixture has been washed with water.

The reaction of phosphites with isothiocyanates was studied on the example of the addition of phosphites to methyl and allyl isothiocyanates. In the latter case, the addition of phosphites is possible both at the C = C and N = C bonds. In the first case, esters of γ-isothiocyanopropylphosphinic acid should be formed and in the second, esters of allylamidophosphonothioformic acid

$$(RO)_2POH + CH_2{=}CH{-}CH_2NCS \longrightarrow \begin{cases} \longrightarrow (RO)_2PCH_2CH_2CH_2NCS \\ \qquad \overset{\|}{O} \\ \\ \longrightarrow (RO)_2P - C \overset{S}{\underset{NHCH_2CH=CH_2.}{\diagdown}} \\ \qquad \overset{\|}{O} \end{cases}$$
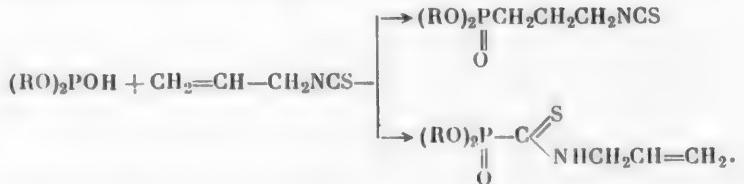
That esters of allylamidophosphonothioformic acid were obtained in the given case was proved by the fact that hydrolysis of the reaction products by heating with hydrochloric acid formed phosphoric acid. The latter was isolated in the form of the trianiline salt. A mixed melting point of this salt with the trianiline salt obtained from orthophosphoric acid and aniline was not depressed. Phosphoric acid could only have been obtained by hydrolysis of the ester of allylamidophosphonothioformic acid and not from the ester of γ-isothiocyanopropylphosphinic acid.

Formula of substance	Boiling point (pressure in mm)	d_4^{20}	n_D^{20}	Yield (in %)	Calculated (in %) Found (in %)		
					P	S	N
CH₃NH\\S⁄C—P(OC₂H₅)₂‖O Methylamide of diethyl phosphonothioformic acid	133—134° (0.2)	1.1820	1.4998	54.4	14.68 / 14.89	15.15 / 15.35	6.64 / 7.00
CH₃NH\\S⁄C—P(OC₃H₇-iso)₂‖O Methylamide of diisopropyl phosphonothioformic acid	113—113.5 (0.08)	1.1167	1.4947	46.3	12.95 / 12.84	13.38 / 13.86	5.86 / 6.64
CH₃NH\\S⁄C—P(OC₄H₉-n)₂‖O Methylamide of di-n-butyl phosphonothioformic acid	140.5 (0.05)	1.0858	1.4940	57.7	11.60 / 11.53	11.97 / 12.24	5.24 / 5.93
CH₂=CHCH₂NH\\S⁄C—P(OC₂H₅)₂‖O Allylamide of diethyl phosphonothioformic acid	125—126 (0.07)	1.1422	1.5120	47.3	13.07 / 12.86	13.51 / 13.85	5.91 / 6.79
CH₂=CHCH₂NH\\S⁄C—P(OC₃H₇-iso)₂‖O Allylamide of diisopropyl phosphonothioformic acid	123—124 (0.05)	1.0950	1.5000	46.4	11.69 / 11.34	12.07 / 12.03	5.28 / 5.71

Esters of alkylamidophosphonothioformic acid are immobile, yellow liquids with a strong, unpleasant smell, and which are readily soluble in organic solvents and insoluble in water; when heated with hydrochloric acid (1:1), they are hydrolyzed to orthophosphoric acid. When esters of alkylamidophosphonothioformic acid are heated for a short time in a solvent with phosphorus pentachloride, rupture of the molecule at the C—P bond occurs and dialkyl chlorophosphates are formed in good yield. The constants of the substances obtained for the first time are presented in the table.

EXPERIMENTAL*

To an equimolecular mixture of dialkyl phosphite and alkyl mustard oil was added an alcohol solution of sodium ethylate until the mixture began to evolve heat, and then the reaction mixture was heated at 105-110° for 2 hours. The cooled reaction mixture was washed with water and the substance extracted with ether. The ether solution was separated and dried over Na_2SO_4. After removal of the solvent, the esters of alkylamides of phosphonothioformic acid were isolated by fractionation of the residue in vacuum.

Hydrolysis of methylamide of diethyl ester of phosphonothioformic acid. To 3.6 g of the substance was added 20 ml of hydrochloric acid (1:1). The mixture was heated under reflux on a boiling water bath for 6 hours, and for 2 hours at 120-130°. After the heating, the aqueous solution was evaporated under reduced pressure. The residue was treated with excess freshly distilled aniline to isolate the acid in the form of the aniline salt. The salt isolated was recrystallized from anhydrous alcohol. After three recrystallizations, the substance isolated had m.p. 175-176° and corresponded in phosphorus and nitrogen content to the trianiline salt of orthophosphoric acid.

Found %: N 10.85, 10.66; P 9.08. $C_{18}H_{24}O_4N_3P$. Calculated %: N 11.12; P 8.23.

* With the participation of L. M. Novskii.

The trianiline salt of orthophosphoric acid formed lustrous, scaly crystals, which were readily soluble in water and hot alcohol, and difficultly soluble in ether, chloroform, and carbon tetrachloride. A mixed melting point of the salt with the trianiline salt of orthophosphoric acid, prepared from pure orthophosphoric acid with aniline, was not depressed.

Reaction of methylamide of diethyl ester of phosphonothioformic acid with phosphorus pentachloride. With vigorous stirring, 11.6 g of phosphorus pentachloride was added in small portions to 11.7 g of the methylamide of the diethyl ester of phosphonothioformic acid in 25 ml of dry carbon tetrachloride, and the reaction mixture heated for 2 hours at 60-65°. The unreacted phosphorus pentachloride was decomposed with sulfur dioxide. The solvent was removed under reduced pressure. On distillation of the residue, a fraction was collected with b.p. 50-60° (0.4 mm), d^{20}_4 1.1995, $n^{20}D$ 1.4205, which did not contain sulfur or nitrogen, and corresponded to diethyl chlorophosphate in constants and chlorine content. The yield of diethyl chlorophosphate was 59.5% (on the methyl-amide of the diethyl ester of phosphonothioformic acid taken for the reaction).

Found %: Cl 20.46. $C_4H_{10}O_3PCl$. Calculated %: Cl 20.58.

Constants reported in the literature [6] for diethyl chlorophosphate: b.p. 61-63° (2.5 mm), d^{20}_4 1.2005, $n^{20}D$ 1.4191.

SUMMARY

It was established that dialkyl phosphites add to methyl and allyl isothiocyanates in the presence of sodium ethylate with the formation of esters of alkylamidophosphonothioformic acid.

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MIXED ANHYDRIDES OF CARBOXYLIC ACIDS AND ACID ESTERS
OF PHOSPHORIC AND METHYLPHOSPHINIC ACIDS
NEW METHOD OF PREPARING PYROPHOSPHATES

K. A. Petrov and A. A. Neimysheva

Original article submitted August 9, 1958

Organic derivatives of anhydrides of phosphorus acids are an important group of phosphorus-containing substances. Among them are known a large number of physiologically active compounds, of which some occupy an important place in biochemical processes, and others are used in agriculture as insecticides. Of the substances with the structure indicated, the pyrophosphates and thiopyrophosphates have been studied comparatively well, while mixed anhydrides formed from carboxylic and phosphorus acid residues have been studied less. At the present time, mixed anhydrides of carboxylic acids and esters of phosphorous acid (dialkyl acylphosphites) and anhydrides of carboxylic acids and esters of thionephosphoric acid (dialkyl acylthionephosphates) are among the substances of this type that are known. Dialkyl acylphosphates were obtained by cleavage of esters of pyrophosphorous acid with carboxylic acids [1] and dialkyl acylthionephosphates by acylation of sodium dialkylthionephosphates with acetyl chloride [2,3] and also by the action of sodium salts of carboxylic acids on dialkyl thionechlorophosphates [4], or by the addition of sulfur to dialkyl acylphosphites [1,2]. All the acylphosphates obtained were found to be liquids which distilled in vacuum. The structure of these substances was confirmed solely by analysis data on the phosphorus, carbon, and hydrogen contents; no analysis for acyl groups was made, and sometimes different constants were given for the same substances, obtained by different methods. Thus, according to the data of M. I. Kabachnik, diethyl acetylthionephosphate is a liquid with b.p. 89-90° (4 mm) [2], while, according to the data of N. I. Zemlyanskii, the substance melts at 64° [4].

As regards the mixed anhydrides of carboxylic acids and derivatives of phosphoric acid, Schrader reported (without giving the constants) dimethylamidodiacetylphosphate and ethyl dimethylamidoacetylphosphate [5], which he obtained by the action of sodium acetate on the diacid chloride of dimethylamidophosphoric acid (the first in an inert solvent, and the second in anhydrous alcohol).

The present work is devoted to the synthesis and a study of the properties of previously undescribed dialkyl acylphosphates. These substances were obtained by the action of silver salts of carboxylic acids on acid chlorides of phosphoric and alkylphosphinic esters in an inert solvent at 35-40°. At the end of the reaction, which was determined from the absence of chlorine from the solution, the precipitate was separated and the solvent distilled from the filtrate in vacuum at room temperature. The residue was practically pure acylphosphate, which was analyzed for the acetyl group and phosphorus contents without additional treatment. In all cases, the substances were obtained in quantitative yield.

In contrast to dialkyl acylthionephosphates, dialkyl acylphosphates were thermally unstable substances. During vacuum distillation they were decomposed quantitatively to form esters of pyrophosphoric acid and the anhydride of the carboxylic acid by the equation

$$2(RO)_2P\underset{OCOCH_3}{\overset{O}{\diagdown}} \xrightarrow{t°} (RO)_2P-O-P(OR)_2 + (CH_3CO)_2O.$$
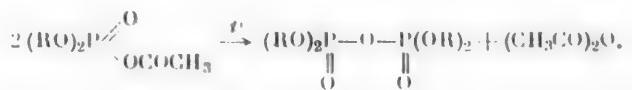
We used this property of acylphosphates for the synthesis of various pyrophosphates, which could also be obtained in one stage without isolation of the acylphosphates. The reaction of the acid chlorides of phosphorus esters with silver acetate was carried out in benzene with heating; after removal of the precipitate and solvent, the residue was fractionated to give acetic anhydride and esters of pyrophosphoric acid. The same results were obtained by using lead acetate in the reaction instead of the silver salt. The yield of pyrophosphates was 90-95%.

Tetraethyl pyrophosphate was obtained in good yield by the action of silver or lead carbonate on diethyl chlorophosphate. In this case, the formation of the pyrophosphate may have proceeded through the mixed anhydride of carbonic and diethylphosphoric acids.

$$2 \begin{array}{c} C_2H_5O \\ C_2H_5O \end{array}\!\!>\!\!P\!\!<\!\!\begin{array}{c} O \\ Cl \end{array} + PbCO_3 \rightarrow \left[\begin{array}{c} C_2H_5O \\ C_2H_5O \end{array}\!\!>\!\!\underset{\underset{O}{\|}}{P}\!-\!O\!-\!\underset{\underset{O}{\|}}{C}\!-\!O\!-\!\underset{\underset{O}{\|}}{P}\!<\!\!\begin{array}{c} OC_2H_5 \\ OC_2H_5 \end{array} \right] + PbCl_2$$

$$\downarrow$$

$$\begin{array}{c} C_2H_5O \\ C_2H_5O \end{array}\!\!>\!\!\underset{\underset{O}{\|}}{P}\!-\!O\!-\!\underset{\underset{O}{\|}}{P}\!<\!\!\begin{array}{c} OC_2H_5 \\ OC_2H_5 \end{array} + CO_2$$
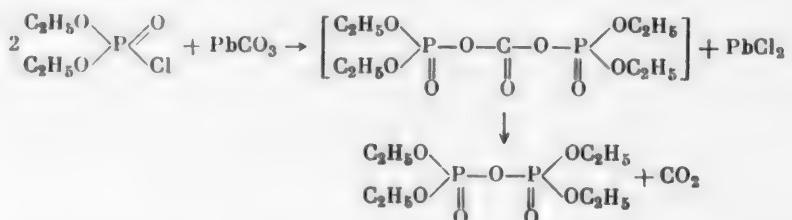
Attempts to replace lead and silver acetates by the potassium and sodium salts did not lead to positive results: in this case, the pyrophosphates were obtained in insignificant yields.

The symmetrical dimethyl ester of methylpyrophosphinic acid and the diethyl ester of the tetraethyldiamide of pyrophosphinic acid were obtained in low yield by any of the methods described. In the first case, the low yield may be explained by the thermal instability of the pyrophosphate. In addition to giving acetic anhydride and methyl methylpyrophosphinate, distillation of the reaction products, obtained by the action of silver acetate on the acid chloride of the methyl ester of methylphosphinic acid, yielded a substance with b.p. 120° (40 mm) or 179-180° (760 mm), which was found to be dimethyl methylphosphinate, and a small amount of the anhydride of methylphosphinic acid remained in the flask. Repeated distillation of methyl methylpyrophosphinate again yielded a certain amount of dimethyl methylphosphinate and the anhydride of methylphosphinic acid. The reaction may be represented by the following scheme:

$$\begin{array}{c} CH_3O \\ CH_3 \end{array}\!\!>\!\!\underset{\underset{O}{\|}}{P}\!-\!O\!-\!\underset{\underset{O}{\|}}{P}\!<\!\!\begin{array}{c} OCH_3 \\ CH_3 \end{array} \longrightarrow CH_3PO(OCH_3)_2 + CH_3PO_2.$$
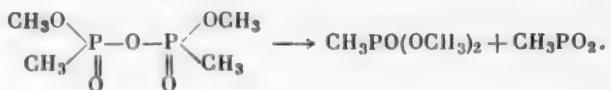
The same results were obtained in the distillation of the previously prepared mixed anhydride of acetic acid and methyl ester of methylphosphinic acid.

The decomposition of the methyl ester of methylpyrophosphinic acid is similar to the thermal decomposition of tetramethyl pyrophosphate and tetraethyl pyrophosphate. It is known that these substances are decomposed with the formation of trialkyl phosphate and alkyl metaphosphate [6].

The formation of pyrophosphates in the thermal decomposition of acylphosphates was observed only when the acylphosphates did not contain alkylamide groups. Alkylamidoacylphosphates decomposed by another scheme. Thus, after many hours' heating of the acid chloride of tetramethyldiamidophosphoric acid with silver acetate in chlorobenzene and subsequent fractional distillation of the reaction mass in vacuum, instead of the expected pyrophosphate we isolated a substance with b.p. 77-79° (24 mm), which was found to be N,N-dimethylacetamide. This substance was evidently obtained as a result of thermal decomposition of the initially formed acylphosphate.

$$\begin{array}{c} (CH_3)_2N \\ (CH_3)_2N \end{array}\!\!>\!\!P\!\!<\!\!\begin{array}{c} O \\ OCOCH_3 \end{array} \overset{t°}{\rightarrow} CH_3C\!\!\underset{N(CH_3)_2}{\overset{O}{\big<}} + (CH_3)_2NPO_3.$$
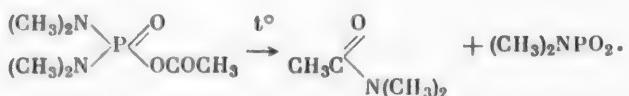
Similar processes also occurred in the preparation of diethyl tetraethyldiamidopyrophosphate. For the reasons given above, the action of the acid chloride of diethylamidoethylphosphate on silver acetate gave the pyrophosphate in not more than 38% yield.

Dialkyl acylphosphates and dialkylacylphosphonates. To a mixture of 0.11 mole of the silver salt of carboxylic acid in 50 ml of absolute ether was added 0.1 mole of chlorophosphate dropwise, and the reaction mixture was stirred at 35-40° until chlorine ion was absent from a test sample. In individual cases, the reaction was continued for from 6 hours to several days. At the end of the reaction, the precipitate was removed, the ether distilled from the filtrate in vacuum at room temperature, and the residue kept in vacuum. The acylphosphates thus obtained were analyzed without further purification. The yield was quantitative. The constants of the substances obtained are presented in Table 1.

TABLE 1

Substance	d_0^t	n_D^t	Calculated (%)		Found (%)	
			CH_3CO	P	CH_3CO	P
$(CH_3O)_2POCOCH_3$ $\|$ O Dimethyl acetylphosphate	1.2990 (20)	1.4070 (28)	25.6	18.45	25.97	18.26
$(C_2H_5O)_2POCOCH_3$ $\|$ O Diethyl acetylphosphate	1.1678 (21)	1.4117 (17)	21.94	15.81	21.75	15.69
CH_3 CH_3O $>POCOCH_3$ $\|$ O Methyl acetylmethyl-phosphonate	1.2618 (14)	1.4212 (14)	28.31	20.40	27.65	19.72
CH_3 n.-C_3H_7O $>POCOCH_3$ $\|$ O n-Propyl acetylmethyl-phosphonate	1.3120 (20)	1.4566 (20)	23.90	17.22	22.10	16.02
$(C_2H_5O)_2POCOCF_3$ $\|$ O Diethyl trifluoroacetyl-phosphate*	1.3074 (17.5)	1.3750 (19)	—	12.40	—	12.74
$(C_2H_5O)_2POCOC_6H_5$ $\|$ O Diethyl benzoylphosphate *	1.1900 (16)	1.4910 (16)	—	12.08	—	11.83

*Found %: F 22.80. $C_6H_{10}O_5PF_3$. Calculated %: F 22.55.

The acyl phosphates were clear, almost colorless liquids, which were readily soluble in organic solvents, and reacted with water and alcohols to form acids and full esters of phosphoric or alkylphosphinic acids, respectively. They were thermally unstable and when vacuum distillation was attempted, they decomposed quantitatively with the formation of pyrophosphates and anhydrides of carboxylic acids.

Reaction of the acid chloride of the tetramethyldiamide of phosphoric acid with silver acetate. 17 g of the acid chloride of the tetramethyldiamide of phosphoric acid, and 20 g of dry silver acetate in 50 ml of anhydrous benzene were stirred and heated at 100° until chlorine ion was absent from a test sample. After removal of the precipitate and the benzene, the residue was vacuum distilled to give N, N-dimethylacetamide. The b.p. was 77-79° (24 mm). We obtained 6.5 g (74.6% yield).

Found %: N 15.78. C_4H_9ON.

Calculated %: N 16.09.

B.p. 83-84° (32 mm) is reported in the literature for N,N-dimethylacetamide.

TABLE 2

Substance	Yield (%)	Boiling point (pressure in mm)	d_0^t	n_D^t	P content, (%)	
					calc.	found
$(C_2H_5O)_2P-O-P(OC_2H_5)_2$ (with =O) Tetraethyl pyrophosphate	90	144—145° (3)	1.2110 (0)	1.4225 (18)	21.38	21.06
$(iso\text{-}C_3H_7O)_2P-O-P(OC_3H_7\text{-}iso)_2$ (with =O) Tetraisopropyl pyrophosphate	54	140—141 (2.5)	1.0850 (20.5)	1.4200 (20.5)	17.90	17.34
$\begin{smallmatrix}C_2H_5O\\(C_2H_5)_2N\end{smallmatrix}P-O-P\begin{smallmatrix}OC_2H_5\\N(C_2H_5)_2\end{smallmatrix}$ Diethyl tetraethyldiamido-pyrophosphate	38	153—153.5 (2)	1.2102 (18)	1.4402 (18)	18.02	17.80
$\begin{smallmatrix}CH_3\\CH_3O\end{smallmatrix}P-O-P\begin{smallmatrix}CH_3\\OCH_3\end{smallmatrix}$ Dimethyl dimethylpyro-phosphinate		137.5—138 (4)	1.3178 (17)	1.4370 (17)	30.69	30.40
$\begin{smallmatrix}CH_3\\n\text{-}C_3H_7O\end{smallmatrix}P-O-P\begin{smallmatrix}CH_3\\OC_3H_7\text{-}n\end{smallmatrix}$ Di-n-propyl dimethyl-pyrophosphinate	73	143—144 (2)	1.2212 (18)	1.4340 (18)	24.11	23.94

Pyrophosphates and pyrophosphonates. The reaction mixture, consisting of 0.1 mole of the acid chloride of the phosphoric or methylphosphinic ester, 0.13 mole of dry silver acetate, and 100 ml of anhydrous benzene, was stirred and heated on a boiling water bath for 6-8 hours. The end of the reaction was determined from the absence of chlorine ion from a test sample. After removal of the precipitate, the benzene was also removed under reduced pressure and the residue fractionated; this always gave two fractions: the first was acetic anhydride and the second did not contain acetyl groups and was esters of pyrophosphoric acid or methylpyrophosphinic acid. The acetanilide obtained from the acetic anhydride isolated melted at 115°, which agrees with the melting point of acetanilide presented in the literature. The constants of the pyrophosphates thus obtained are presented in Table 2.

Tetraethyl pyrophosphate was obtained similarly if the silver acetate was replaced in the reaction by lead acetate (yield 94%), silver carbonate (yield 78%), or lead carbonate (yield 64%). The reaction of diethyl chlorophosphate with lead salts proceeded more slowly and was complete after 18-20 hours.

The acid chloride of ethyl diethylamidophosphate was reacted with silver acetate in chlorobenzene; when the reaction was carried out in benzene, acetonitrile or glacial acetic acid, no formation of pyrophosphate was observed.

The pyrophosphates and pyrophosphonates were soluble in organic solvents, hydrolyzed by water with difficulty, and did not interact with alcohols. Thus, after boiling di-n-propyl dimethylphosphinate with n-propyl alcohol for 2 hours, we recovered the starting materials quantitatively.

The pyrophosphates were thermally unstable: tetraisopropyl pyrophosphate decomposed completely at 190°, diethyl tetraethyldiamidopyrophosphate at 230-240°, and the dimethyl ester of dimethylpyrophosphinic acid decomposed even when vacuum distilled; two fractions were then isolated, the first boiling at 120-141° (40 mm), and the second at 141-142° (4 mm). A sirupy liquid remained in the distillation flask, and this was the anhydride of methyl phosphinic acid. The first fraction boiled at 179-180° at atmospheric pressure, and was found to be dimethyl methylphosphinate.

Found %: P 24.10. $C_3H_9O_3P$.

Calculated %: P 25.00.

The second fraction was dimethyl methylpyrophosphinate.

SUMMARY

1. A method was developed for preparing dialkyl acylphosphates by the action of silver salts of carboxylic acids on the acid chlorides of esters of phosphorus acids.

2. It was established that on heating, dialkyl acylphosphates decomposed quantitatively to form pyrophosphates and anhydrides of carboxylic acids.

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* Original Russian pagination. See C.B. translation.

ESTERS OF ALKYLCYANOPHOSPHINIC ACIDS

K. A. Petrov, L. G. Gatsenko and A. A. Neimysheva

Original article submitted March 20, 1958

The most important mode of synthesizing esters of phosphonic acids is Arbuzov's method, which consists of alkylating neutral phosphites with alkyl halides. This method has been used to prepare a large number of different esters of phosphonic acids, containing various functional groups in the radical attached directly to the phosphorus. There is some similarity between the reaction considered and the reaction of phosphites and halophosphites with halides, sulfenyl chlorides, chloroamines, alkyl hypochlorites [1], etc. In contrast to the alkylation of neutral phosphites, in the latter case phosphonates are not obtained, but phosphates, amidophosphates, halophosphates, thiophosphates, and other similar compounds.

In the present work, a study was made of the action of alkyl halides on dialkyl cyanophosphites. It was surmised that the reaction would proceed in accordance with the "Arbuzov rearrangement," as a result of which esters of alkylcyanophosphinic acids would be obtained.

$$(RO)_2PCN + R'I \longrightarrow \left[(RO)_2P \underset{I}{\overset{CN}{\underset{R'}{\langle}}} \right] \longrightarrow \underset{RO}{\overset{R'}{\rangle}} P \underset{CN}{\overset{O}{\langle}} + RI$$
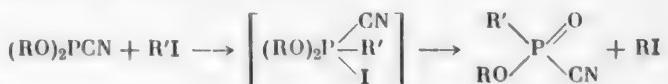
Experiments confirmed our surmise. Thus, when di-n-propyl cyanophosphite was heated in a sealed tube with three to four times the amount of methyl iodide for 8-10 hours at 160°, the n-propyl ester of methylcyanophosphinic acid was obtained in 80% yield. The structure of the cyanide obtained was confirmed by analysis for phosphorus and the CN group, and its conversion into methylphosphinic acid on hydrolysis. A mixed melting point of the methylphosphinic acid obtained with the acid prepared by hydrolysis of the methyl ester of methylphosphinic acid was not depressed. The acid was isolated in the form of the free acid and as its aniline salt.

The action of chlorine on n-propyl methylcyanophosphinate in the presence of an equimolecular amount of phosphorus trichloride formed the diacid chloride of methylphosphinic acid. The melting and boiling points agreed with those given in the literature for this substance [2].

$$\underset{CH_3}{\overset{n-C_3H_7O}{\rangle}} P \underset{CN}{\overset{O}{\langle}} + PCl_3 + 2Cl_2 \longrightarrow CH_3POCl_2 + n\text{-}C_3H_7Cl + POCl_3 + ClCN$$
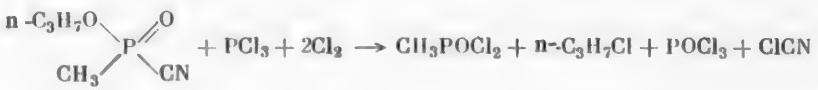
The method proposed for preparing esters of alkylcyanophosphinic acids is a general one, and convenient for preparing any esters of alkylcyanophosphinic acids. By the action of various alkyl halides on the same ester of cyanophosphorous acid it is possible to obtain esters of different alkylcyanophosphinic acids, differing from each other in the alkyl residues attached directly to the phosphorus. By the action of the same alkyl halide on different esters of cyanophosphorous acids, one may form different esters of the same alkylcyanophosphinic acid.

The esters of alkylcyanophosphinic acids were colorless liquids, which dissolved in organic solvents; they were readily hydrolyzed by water and alkalis; the cyano group was determined quantitatively by Liebig's method.

The starting dialkyl cyanophosphites were obtained by replacement of the chlorine in dialkyl chlorophosphites by the CN group by means of silver cyanide in dry ether with heating. The action of silver cyanide on alkyl dichlorophosphites also yielded alkyl dicyanophosphites. This method was used previously for preparing cyanides of alkyl- and dialkylphosphinous acids [3].

The alkyl cyanophosphites were colorless liquids with the unpleasant smell of phosphines, and were soluble in organic solvents; they were readily hydrolyzed by water and aqueous solutions of alkalis; they formed solid complex salts with cuprous chloride.

EXPERIMENTAL

Diethyl cyanophosphite. To 21.5 g of diethyl chlorophosphite, dissolved in 50 ml of dry ether, was added 23.6 g of thoroughly dried and finely ground silver cyanide. The reaction mixture was heated and stirred vigorously for 12 hours. The silver chloride formed and excess silver cyanide were removed by filtration and washed several times with dry ether. The ether was distilled from the filtrate on a Widmer column. The residue was vacuum distilled in a stream of CO_2, using a still head. We obtained 9.6 g (47.5%) of cyanide.

B. p. 51-52° (5 mm), 69-70° (15 mm), d_{20}^{20} 1.0220, $n^{22}D$ 1.6675.

Found %: CN 17.66. $C_6H_{10}O_2NP$.

Calculated %: CN 17.69.

The ester was a colorless liquid with an unpleasant, bitter smell, and was soluble in ether, benzene, carbon tetrachloride, acetone, alcohols, and other organic solvents. The cyanide was hydrolyzed by water and alkalis; the cyano group was determined quantitatively by the method of Liebig and Denige.

Diisopropyl cyanophosphite was obtained under analogous conditions. The yield was 44%. The b.p. was 62-64° (8 mm).

Found %: CN 15.02. $C_7H_{14}O_2NP$.

Calculated %: CN 14.86.

Di−n propyl cyanophosphite. The yield was 50%.

B.p. 80-82° (6 mm), $d_{24.5}^{24.5}$ 0.9833, $n^{24.5}D$ 1.4270.

Found %: P 17.5; N 8.12; CN 14.88. $C_7H_{14}O_2NP$.

Calculated %: P 17.7; N 8.0; CN 14.85.

n-Propyl dicyanophosphite. To 32 g of n-propyl dichlorophosphite, dissolved in 100 ml of anhydrous benzene, was added 70 g of dried silver cyanide, and the reaction mixture heated at 80-84° for 7 hours. After the heating, the dicyanide was isolated by fractionation in vacuum. We obtained 20.0 g (70%).

B.p. 61° (5 mm), d^{20}_{20} 1.0955, $n^{20}D$ 1.4586.

Found %: CN 36.7. $C_5H_7ON_2P$.

Calculated %: CN 36.6.

The cyanide was a colorless liquid with an unpleasant, bitter smell, and was soluble in benzene, chloroform, carbon tetrachloride, and other organic solvents. During storage, the substance gradually decomposed and acquired a reddish color, apparently due to precipitation of red phosphorus. The cyanide was decomposed vigorously by water and the cyano group was determined quantitatively by Liebig's method. The cyanide reacted vigorously with cuprous chloride to form a complex salt, which appeared as a white crystalline substance, soluble in acetonitrile, but insoluble in chloroform, carbon tetrachloride, benzene, and ether. Hypothetically, the complex salt had the following composition: n-$C_3H_7OP(CN)_2$ · CuCl or [n-$C_3H_7OP(CN)_2$]$_2$ · CuCl.

Ethyl dicyanophosphite was obtained under analogous conditions.

B.p. 51.5-52° (5 mm), d_{20}^{20} 1.1349, $n^{20}D$ 1.4535.

Found %: CN 40.18. $C_4H_5ON_2P$.

Calculated %: CN 40.62.

n-Propyl methylcyanophosphinate. 17.5 g of di-n-propyl cyanophosphite and 70 g of methyl iodide were heated in a sealed glass tube at 160° for 8-10 hours. After the heating, the methyl iodide and n-propyl iodide were distilled from the reaction mass at normal pressure, and the residue was vacuum distilled. We obtained 11.7 g (80%) of product.

B.p. 95° (6 mm), $d_4^{24.5}$ 1.0385, $n^{24.5}$ D 1.4125.

Found %: P 21.18; N 9.78; CN 17.86. $C_5H_{10}O_2NP$.

Calculated %: P 21.10; N 9.53; CN 17.69.

In the alkylation of di-n-propyl cyanophosphite at 130°, the formation of n-propyl methylcyanophosphinate was also observed, but the yield of it was insignificant.

n-Propyl methylcyanophosphinate was a colorless liquid with the smell of hydrocyanic acid, and was soluble in water and organic solvents. The cyanide was readily hydrolyzed by water and alkalis. The cyano group was determined quantitatively by Liebig's method. The ester reduced permanganate in aqueous solutions due to hydrocyanic acid, formed as a result of hydrolysis of the cyanide. The cyanide decomposed when treated with cuprous chloride. The formation of a complex salt with cuprous chloride, which is characteristic of phosphines, was not observed.

In order to establish the structure of the cyanide, the latter was converted into the acid chloride of methylphosphinic acid and methylphosphinic acid, which was isolated as the free acid and as the aniline salt. The conversion into the acid chloride of methylphosphinic acid was accomplished in the following way: to 10 g of n-propyl methylphosphinate was added 10 g of phosphorus trichloride, and then a stream of chlorine was slowly passed into the reaction mixture for 1-1.5 hours at 20° and for 30 minutes at 60°. The end of chlorination was determined by a negative reaction for trivalent phosphorus with mercuric chloride solution on a test sample. After the chlorination, the reaction mass was distilled at normal pressure. The propyl chloride and phosphorus oxychloride distilled first, and then the acid chloride of methylphosphinic acid at 160-164°. The acid chloride was purified by many distillations; we collected a fraction with b.p. 162°, which crystallized at room temperature. The acid chloride obtained melted at 31-32°. The melting and boiling points of the substance obtained agree with those reported for the diacid chloride of methylphosphinic acid.

The acid chloride was converted into methylphosphinic acid in the following way: the acid chloride was gradually added in small portions to water. The hydrolysis proceeded vigorously with strong evolution of heat. When all the anhydride had been added, the solution was evaporated to dryness in vacuum on a water bath. The methylphosphinic acid, dried in a desiccator over phosphorus pentoxide, melted at 102-103°; a mixed melting point with the acid prepared from methyl methylphosphinate was not depressed.

Hydrolysis of n-propyl methylcyanophosphinate. 1.0 g of ester was dissolved in 8-10 ml of water, and the solution boiled for 1-2 hours and then evaporated to dryness in vacuum. The residue was boiled with 8 ml of concentrated hydrochloric acid (d 1.19) for 4 hours, after which the hydrochloric acid was removed in vacuum. The residue was decolorized by solution in water and heating the solution with animal charcoal, which was then removed by filtration. Evaporation of the filtrate left methylphosphinic acid, which had m.p. 103° without recrystallization. If n-propyl methylcyanophosphinate was heated immediately with concentrated hydrochloric acid, the methylphosphinic acid always contained ammonium chloride, which was obtained due to hydrolysis of hydrocyanic acid, formed by decomposition of the cyanide. The methylphosphinic acid obtained was converted into the aniline salt. With this aim, the calculated amount of aniline in n-propyl alcohol was added to methylphosphinic acid. The aniline salt precipitated as snow white crystals. After recrystallization from n-propyl alcohol, and drying in a desiccator over phosphorus pentoxide, the substance had m.p. 149-150°. A mixed melting point with the aniline salt of methylphosphinic acid, prepared from methyl methylphosphinate, was not depressed.

Ethyl methylcyanophosphinate. 7.2 g of diethyl cyanophosphite and 29 g of methyl iodide were heated in a sealed tube at 160° for 8 hours. Ethyl methylcyanophosphinate was isolated from the reaction mixture.

B.p. 73-74° (3 mm), d_{20}^{20} 1.1084, n^{19}D 1.4205.

Found %: CN 19.88. $C_4H_8O_2NP$.

Calculated %: CN 19.55.

The aniline salt of methylphosphinic acid, obtained as a result of hydrolysis of ethyl methylcyanophosphinate and subsequent treatment with aniline, melted at 149°. A mixed melting point with the aniline salt, prepared from pure authentic methylphosphinic acid, was not depressed.

Ethyl ethylcyanophosphinate. 8.5 g of diethyl cyanophosphite was heated with 22 g of ethyl iodide in a sealed tube at 160° for 10 hours. Ethyl ethylcyanophosphinate was isolated from the reaction mixture.

B.p. 79-80° (5 mm), d_{20}^{20} 1.0795, $n^{20}D$ 1.4196.

Found %: CN 17.63. $C_5H_{10}O_2NP$.

Calculated %: CN 17.69.

The substance was a colorless substance, which was soluble in organic solvents. The cyanide was readily hydrolyzed by alkalis and water. In order to prove the structure of the cyanide obtained, the latter was converted into the aniline salt of ethylphosphinic acid. The experiment was carried out under conditions analogous to those described for the aniline salt of methylphosphinic acid. The m.p. was 143-144°, and the substance crystallized from ethyl and propyl alcohols, was readily soluble in water and hot alcohol, difficultly soluble in cold alcohol, and did not dissolve in ether.

Found %: N 6.81. $C_8H_{14}O_3NP$.

Calculated %: N 6.89.

n-Propyl n-propylcyanophosphinate. 8.7 g of di-n-propyl cyanophosphite and 30 g of n-propyl iodide were heated in a sealed glass tube at 160-170° for 10-12 hours. After the heating, the contents of the tubes were distilled to yield n-propyl n-propylcyanophosphinate.

B.p. 99-102° (5 mm), d_{20}^{20} 1.0135, $n^{20}D$ 1.4300.

Found %: CN 15.0. $C_7H_{14}O_2NP$.

Calculated %: CN 14.85.

The ester was a colorless liquid, which was difficultly soluble in water and readily soluble in organic solvents. The cyanide was hydrolyzed by water and alkalis; the cyano group was determined quantitatively by Liebig's method. Hydrolysis converted the ester into n-propylphosphinic acid, which was isolated in the form of the free acid and as the ammonium salt under conditions analogous to those presented in the description of the hydrolysis of n-propyl methylcyanophosphinate. The n-propylphosphinic acid melted at 66°.

Found %: N 10.13. $C_3H_{12}O_3NP$.

Calculated %: N 9.94.

After recrystallization from n-propyl alcohol, the ammonium salt melted at 223-225°; it formed white needles, which were readily soluble in hot ethyl and propyl alcohols, and difficultly so in cold alcohols.

SUMMARY

1. Esters of cyanophosphorous and dicyanophosphorous acids, which have not been described in the literature previously, were prepared.

2. An investigation was made of the alkylation of cyanophosphorous esters with alkyl halides, and previously undescribed esters of alkylcyanophosphinic acids were obtained.

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*Original Russian pagination. See C.B. translation.

INVESTIGATIONS IN THE FIELD OF THE TETRACYCLINES

IV. STUDY OF METHODS OF SYNTHESIZING THE TRICYCLIC SYSTEM DCB OF TETRACYCLINES*

M. M. Shemyakin, M. N. Kolosov, Yu. A. Arbuzov,

M. G. Karapetyan, E. S. Chaman and A. A. Onishchenko

Institute of Biological and Medical Chemistry, Academy of Medical Sciences, USSR
and Institute of Organic Chemistry, Academy of Sciences, USSR

The structure of the widely known tetracyclines (I) has a series of characteristic peculiarities, determining both the routes and methods by which the total synthesis of this type of compound may be achieved. Due to the presence of a β-polycarbonyl system, the tetracyclines are very sensitive to alkaline reagents, which readily produce hydrolytic cleavage to iso-compounds, and then further decomposition. The presence of a tertiary hydroxyl in ring C causes the tendency of tetracyclines to acid-catalyzed dehydration, leading to aromatization of ring C and formation of an anhydro-compound.

$R^1 = H, Cl$ or Br; $R^2 = H$ or OH
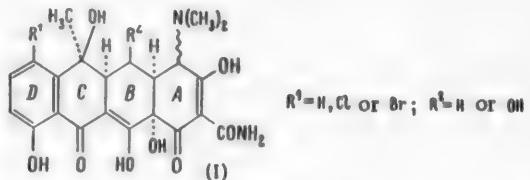
In this connection, it is advantageous to build up the specific ring system of tetracyclines in such an order that those groups which make the molecule labile are formed in the latest possible steps of the synthesis. However, the formation of the methylcarbinol group in ring C can only be achieved comparatively easily in the initial stages of the synthesis, which also should be considered, despite a series of difficulties arising later. From this, there logically follows the plan for synthesizing tetracyclines "from left to right," i.e., first the construction of a sufficiently complete tricyclic system DCB, and then the gradual formation of the most complex ring A.

Starting from these considerations, we planned the synthesis of those ketols of the hydroanthracene series of type (III) and (IV), in which two rings would be analogous in structure and sterically to rings D and C of tetracyclines, and the third ring would contain the structural prerequisites for subsequent construction of ring A and the introduction of the necessary functional groups into ring B of the tetracyclines. The route we chose for synthesizing compounds of this type consisted of the condensation of 1,4-naphthoquinone with butadiene or its derivatives, and conversion of the adducts (II) formed into ketols (III), which are then hydrolyzed under mild conditions to hydroxydiketones (IV).

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*For communications I-III, see [1-3].

R = H, OCH₃ or OAc;
R' = H or OCH₃

(IIa) R = R' = H; (IIb) R = H, R' = OCH₃;
(IIc) R = OCH₃, R' = H; (IId) R = OAc, R' = H;
(IIe) R = R' = OCH₃.

(IIIa) R = R' = H; (IIIb) R = H, R' = OCH₃;
(IIIc) R = OCH₃, R' = H; (IIId) R = R' = OCH₃.

(IVa) R = H; (IVb) R = OCH₃.
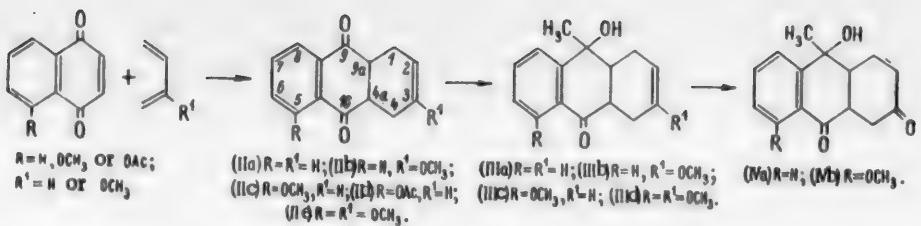
The first stage of the synthesis, the diene condensation, was readily accomplished and proceeded in high yields when naphthoquinone was heated with excess diene in alcohol or benzene at 100°. It should be noted, however, that for this reaction it was necessary to use carefully purified quinones, as otherwise there was considerable polymerization of the dienes and the yield of adduct (II) fell considerably.

In the condensation of 5-methoxynaphthoquinone with 2-methoxybutadiene, two isomeric adducts were formed, (IIe) and (IIf), approximately in the ratio of 4:1. To prove their structures, these compounds were oxidized with atmospheric oxygen in alcoholic alkali solution to 1,7- and 1,6-dimethoxyanthraquinone, (VIIc) and (VIId),[*] which were then hydrolyzed to the corresponding dihydroxyanthraquinones (VIIe) and (VIIf), of which the former was found to be identical with 1,7-dihydroxyanthraquinone, obtained from m-hydroxybenzoic acid [4].

(IIa) R = R¹ = R² = H;
(IIb) R = R² = H, R¹ = OCH₃;
(IIc) R = OCH₃, R¹ = R² = H;
(IIe) R = R¹ = OCH₃, R² = H;
(IIf) R = R² = OCH₃, R¹ = H.

(Va) R = OCH₃; R¹ = R² = H.

(VIa) R = R¹ = R² = H;
(VIb) R = OCH₃, R¹ = R² = H;
(VIc) R = R¹ = OCH₃, R² = H.

(VIIa) R = R² = H, R¹ = OCH₃;
(VIIb) R = OCH₃, R¹ = R² = H;
(VIIc) R = R¹ = OCH₃, R² = H;
(VIId) R = R² = OCH₃, R¹ = H;
(VIIe) R = R¹ = OH, R² = H;
(VIIf) R = R² = OH, R¹ = H.
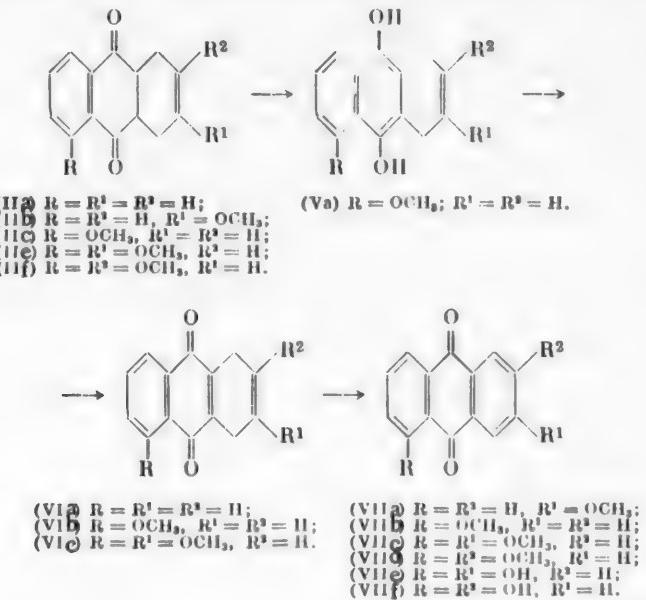
The second stage of the synthesis, namely the selective conversion of the C₉-keto group of the adducts (II) into a tertiary methylcarbinol group, was accompanied by a series of difficulties due to the presence of two reactive carbonyl groups in the molecule, and the tendency of adducts (II) to isomerize into dihydroanthrahydroquinones (V). Thus, with the use of a considerable excess of methylmagnesium halide, and the normal order of mixing the reagents (i.e., addition of the adduct to the organomagnesium compound), the main reaction products were glycols of type (VIII).

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[*] The intermediate stages of the conversion of (II) into (VII) were their isomerization into dihydroanthrahydroquinones (V) and oxidation of the latter into dihydroanthraquinones (VI). Both of these reactions proceeded very readily and, therefore, the action of enolizing agents on the adducts (II) in the presence of atmospheric oxygen always formed certain amounts of dihydroquinones (VI) (the intermediate hydroquinones could only be isolated when oxygen was carefully excluded).

(IIa) R = R¹ = H;
(IIb) R = H, R¹ = OCH₃;
(IIc) R = OCH₃, R¹ = H;
(IIe) R = R¹ = OCH₃.

(IIIa) R = R¹ = H;
(IIIb) R = H, R¹ = OCH₃;
(IIIc) R = OCH₃, R¹ = H;
(IIId) R = R¹ = OCH₃.

(VIIIa) R = R¹ = H;
(VIIIb) R = H, R¹ = OCH₃;
(VIIIc) R = OCH₃, R¹ = H;
(VIIId) R = R¹ = OCH₃.

(IXa) R = H, R¹ = OCH₃;
(IXb) R = R¹ = OCH₃.
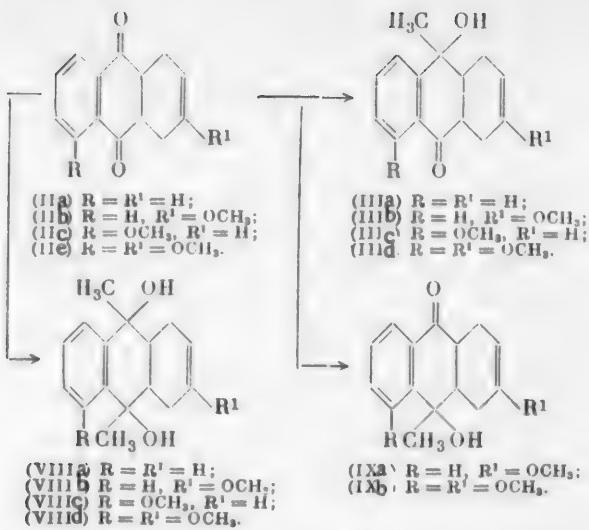
We were able to obtain the desired results only by adding an ether solution of methylmagnesium iodide (not more than 25% excess) in the cold to a benzene solution of adduct (II). Under such optimal conditions, the simplest diketone (IIa) was converted in 70% yield into the unsubstituted keto alcohol (IIIa), the monomethoxy adduct (IIb) formed the hydroxyketones (IIIb) and (IXa), in the case of adduct (IIc), it was only possible to isolate hydroxyketone (IIIc), and the dimethoxy adduct (IIe) yielded two isomeric ketols, (IIId) and (IXb). The structure of the isomeric ketols, formed from adduct (IIb), was not investigated specially, but they apparently had the structures (IIIb) and (IXa), and were not stereoisomers.

For determining the position of the methylcarbinol group in compounds (IIIc), (IIId), and (IXb), we used the general property of ketols of type (III) and (IX), and also of glycols (VIII) for readily undergoing acid-catalyzed dehydration to derivatives of di- and tetrahydroanthracene (X) and (XI) and the structure of the dehydration products was then confirmed by a study of their infrared spectra.

(Xa) R = H, X = OH;
(Xb) R = OCH₃, X = OH;
(Xc) R = H, X = CH₃;
(Xd) R = OCH₃, X = CH₃.

(XIa) R = H, X = Y = CH₃;
(XIb) R = OCH₃, X = OH, Y = CH₃;
(XIc) R = OCH₃, X = CH₃, Y = OH;
(XId) R = OCH₃, X = Y = CH₃.

(XII)
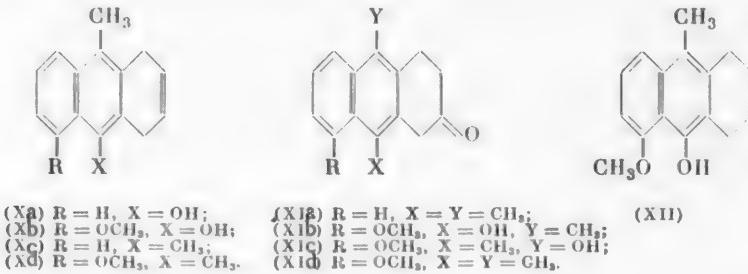
Thus, the tetrahydroanthrol (XIb) and the dihydro derivative (XII) obtained from compound (Xb) showed [5] a displaced and diffuse band of an OH group, characteristic of compounds with an intramolecular hydrogen bond

$CH_3-O \cdots H-O$ (such as 8-methoxynaphthol-1, etc.), and due to this, the structure of 5-methoxy-1,2,3,4-tetrahydroanthrol-10 derivatives must be ascribed to these compounds. The frequency of the OH group band of compound (XIc) coincides with the OH frequency of 5-methoxynaphthol-1, so that this compound can be considered as a derivative of 5-methoxy-1,2,3,4-tetrahydroanthrol-9. It is also necessary to note that the almost complete identity of the ultraviolet spectra of compound (Xb) and its dihydroderivative (XII) indicates that the double bond in compound (Xb) is not conjugated with the aromatic system and, consequently, all the conversions of adducts of type (II) described in this article do not involve migration of the double bond in position 2,3.

The third stage of the synthesis of compounds of type (IV), namely hydrolysis of the enol methoxyl to a keto group, only proceeded satisfactorily when dilute acids were used, since, under the action of conc. HCl, the

corresponding ketols (III) and (IX), and also the glycol (VIII) underwent dehydration simultaneously with the hydrolysis. Selective hydrolysis of the enol methoxyl, without touching the tertiary hydroxyls, was achieved by shaking an ether solution of the substance with 0.3 N HCl at 20° or (as is better) by heating a solution of the substance with 0.03 N aqueous alcoholic HCl at 40°. Under these conditions, ketols (IIIb), (IIId), (IXa), and (IXb) yielded the hydroxydiketones (IVa), (IVb), (XIIIa), and (XIIIb), respectively, and glycols (VIIIb) and (VIIId) gave dihydroxyketones (XIVa) and (XIVb).

(IVa) R = H;
(IVb) R = OCH₃.

(XIIIa) R = H;
(XIIIb) R = OCH₃.

(XIVa) R = H;
(XIVb) R = OCH₃.
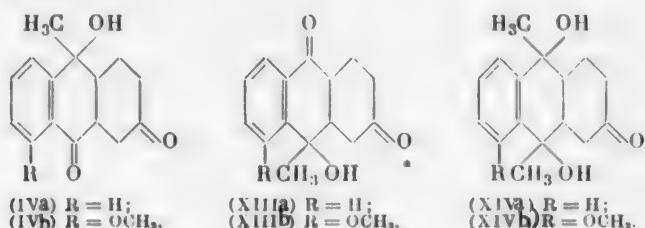
While sensitive to the action of acids, ketols (III) were extremely stable toward alkalis and did not change, even when boiled with a 2% alcohol solution of KOH. This shows that they have the most stable, probably, trans-coupling of the alicyclic rings (cf. the behavior of cis- and trans-α-decalones under analogous conditions [6]); apparently, in the formation of these ketols from adducts (II), epimerization of one of the asymmetric centers (C_{4a} or C_{9a}) occurs since, according to Alder's rule, the starting adducts must have a cis-configuration. As regards the third asymmetric center (C_9), its configuration may be established on the basis of the principle of "steric control by asymmetric induction" [7], according to which the attack on the C_9-carbonyl by the organomagnesium complex must occur predominantly from the least-screened direction, leading to a compound with a trans disposition of the C_9-hydroxyl and the C_{9a}-hydrogen. Hence, it follows that ketols of type (III) and (IV) have the steric structure of (XV), which corresponds completely to the configuration of natural tetracyclines (I) [8]. This conclusion is confirmed by the fact that ketols (III) and (IV) undergo acid dehydration under the same conditions and with the same ease as natural tetracyclines (I); since the ease of these conversions is determined by the steric mutual disposition of the groups eliminated, the identical behavior of ketols (III) and (IV) and the tetracyclines (I) also indicates the identity of the configurations of the corresponding portions of their molecules.

(XV) R=H or OCH₃; Z=CH=CH, CH=C(OCH₃) or CH₃CO
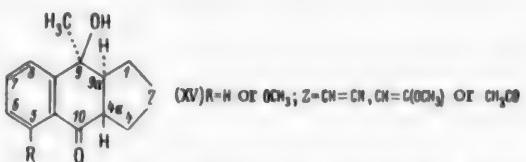
The presence of a reactive double bond, and enol-ether grouping or a carbonyl group in ketols of type (XV) forms the prerequisites for the introduction of various substituents and functional groups into positions 2, 3, and 4 of their molecules, which, in its turn, opens up the possibility of building up ring A of tetracyclines, for example, by the scheme we developed recently [3].

EXPERIMENTAL*

1. Preparation of Adducts of Type (II). General Method

Carefully purified quinone was suspended in alcohol or benzene, freshly distilled diene added, and the mixture heated in a sealed tube or an autoclave with periodic shaking. Adducts (IIa)-(IId) crystallized readily when the reaction mixture was cooled to −20°; for isolation of adducts (IIe) and (IIf), the solvent and excess diene were removed in vacuum and the residue ground with ether, collected by filtration, and carefully washed with ether { see [9] on adduct (IIa)}.

a. 9,10-Diketo-2-methoxy-1,4,4a,9,9a,10-hexahydroanthracene (IIb) was obtained from 0.1 mole of 1,4-naphthoquinone and 0.25 mole of 2-methoxybutadiene in 30 ml of anhydrous alcohol in the presence of 0.1 g of hydroquinone (100°, 4 hours); the yield was 88%.

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* All the ultraviolet spectra were plotted in 96% alcohol and the infrared spectra in CCl₄ (1:400 to 1:600).

M.p. 143-144° (from benzene), λ_{max} 224, 254 and 298 mμ (lg ε 4.43, 3.93, and 3.21).

Found %: C 74.08; H 5.93. $C_{15}H_{14}O_3$.

Calculated %: C 74.36; H 5.83.

b. 9,10-Diketo-5-methoxy-1,4,4a,9,9a,10-hexahydroanthracene (IIc) was obtained from 0.1 mole of 5--methoxy-1,4-naphthoquinone and 0.4 mole of butadiene in 100 ml of alcohol (100°, 1.5 hours); yield 91%.

M.p. 92-93° (from alcohol), λ_{max} 229 and 336 mμ (lg ε 4.41 and 3.73).

Found %: C 74.49; H 5.89. $C_{15}H_{14}O_3$.

Calculated %: C 74.36; H 5.83.

c. 9,10-Diketo-5-acetoxy-1,4,4a,9,9a,10-hexahydroanthracene (IId) was obtained from 0.1 mole of 5--acetoxy-1,4-naphthoquinone and 0.4 mole of butadiene in 200 ml of alcohol (100°, 1.75 hours); the yield was 91% and λ_{max} 223, 245, and 307 mμ (lg ε 4.44, 3.91, and 3.37). The compound existed in two crystalline modifications (α and β), of which the α-form was metastable and readily changed into the β-form when melted or dissolved.

α-Form: m.p. 113.5-114.5° (from alcohol).

Found %: C 71.50; H 5.11. $C_{16}H_{14}O_4$.

Calculated %: C 71.10; H 5.22.

β-Form: m.p. 135.5-136.5° (from alcohol).

Found %: C 71.29; H 5.20. $C_{16}H_{14}O_4$.

Calculated %: C 71.10; H 5.22.

d. 9,10-Diketo-3,5-dimethoxy- and 9,10-diketo-2,5-dimethoxy-1,4,4a,9,9a,10-hexahydroanthracene (IIe) and (IIf) were obtained from 0.1 mole of 5-methoxy-1,4-naphthaquinone and 0.3 mole of 2-methoxybutadiene in 200 ml of anhydrous benzene in an atmosphere of CO_2 (100°, 12 hours); the mixture of adducts (IIe) and (IIf) formed (92% yield) was resolved by fractional recrystallization from benzene.

(IIe): yield 55-60%, m.p. 144-145°, λ_{max} 227 and 338 mμ (lg ε 4.32 and 3.70).

Found %: C 70.72; H 6.13. $C_{16}H_{16}O_4$.

Calculated %: C 70.57; H 5.92.

(IIf): yield 15-20%, m.p. 141-143°, λ_{max} 227 and 338 mμ (lg ε 4.33 and 3.72).

Found %: C 70.59; H 5.87. $C_{16}H_{16}O_4$.

Calculated %: C 70.57; H 5.92.

2. Isomerization and Oxidation of Adducts of Type (II)

a. Isomerization of 9,10-diketo-5-methoxy-1,4,4a,9,9a,10-hexahydroanthracene (IIc). To a solution of 0.3 g of adduct (IIc) in 3 ml of alcohol, shaken in an atmosphere of H_2, was added 10 mg of NaOH and, after 5 minutes, the mixture acidified with 5% HCl and the precipitate collected and washed with water. The yield of 5-methoxy-1,4-dihydro-9,10-anthrahydroquinone (Va) was 0.26 g (87%) and the m.p. 146-148° (from alcohol saturated with CO_2).

Found %: C 74.55; H 5.84. $C_{15}H_{14}O_3$.

Calculated %: C 74.36; H 5.83.

b. Oxidation of 9,10-diketo-5-methoxy-1,4,4a,9,9a,10-hexahydroanthracene (IIc) to 5-methoxy-1,4-dihydroanthraquinone (VIb). To 0.3 g of adduct (IIc) in 3 ml of alcohol was added 0.5 ml of 10% alcohol solution of NaOH and the solution acidified to congo with 10% HCl. To the suspension of hydroquinone obtained was added 3 ml of a saturated solution of $FeCl_3$, and the mixture heated to boiling. On cooling, the precipitate was

removed by filtration and washed with alcohol and ether. The yield of dihydroanthraquinone (VIb) was practically quantitative, and the m.p. 186-187° (from alcohol).

Found %: C 75.00; H 4.97. $C_{15}H_{12}O_3$.

Calculated %: C 74.99; H 5.03.

c. Oxidation of 9,10-diketo-5-methoxy-1,4,4a,9,9a,10-hexahydroanthracene (IIc) to 1-methoxyanthraquinone (VIIb). Air, freed from CO_2, was passed for 5 hours through a suspension of 0.3 g of adduct (IIc) in 30 ml of a 2% alcohol solution of KOH. The precipitate was collected by filtration and washed with water and alcohol. The yield of quinone (VIIb) was 0.25 g (85%) and the m.p. 171° (from alcohol) (cf. [10]).

d. Oxidation of 9,10-diketo-2-methoxy-1,4,4a,9,9a,10-hexahydroanthracene (IIb) to 2-methoxyanthraquinone (VIIa) was carried out as described in experiment 2c. The yield of quinone (VIIb) was 88%, and the m.p. 196° (from alcohol) (cf. [11]).

e. Oxidation of 9,10-diketo-3,5-dimethoxy-1,4,4a,9,9a,10-hexahydroanthracene (IIe) to 1,7-dimethoxyanthraquinone (VIIc) was carried out as described in experiment 2c. The yield of quinone (VIIc) was 90%, and the m.p. 192.5° (from alcohol) (cf. [12]).

0.25 g of this dimethoxyanthraquinone was stirred for 30 min at 160° with 10 ml of 78% H_2SO_4, the solution poured into water, and the precipitate collected by filtration. The yield of 1,7-dihydroxyanthraquinone (VIIe) was 0.18 g (80%). After extraction with hot anhydrous benzene and recrystallization from alcohol, the substance had m.p. 293-294° (in a sealed capillary) (cf. [13]). To 30 mg of this compound in 0.4 ml of Ac_2O was added 0.01 ml of conc. H_2SO_4, the mixture boiled for 2 min, and the precipitate of 1,7-diacetoxyanthraquinone collected by filtration. The yield was 35 mg (86%) and m.p. 197-198° (from glacial AcOH) (cf. [13]). The dihydroxyanthraquinone and its diacetyl derivative obtained did not depress the melting points when mixed with 1,7-dihydroxyanthraquinone and its diacetate, synthesized from m-hydroxybenzoic acid [4].

f. Oxidation of 9,10-diketo-2,5-dimethoxy-1,4,4a,9,9a,10-hexahydroanthracene (IIf) to 1,6-dimethoxyanthraquinone (VIId) was carried out as described in Experiment 2c. The yield of quinone (VIId) was 86%, and the m.p. 189.5-190° (from alcohol) (cf. [12]). The product was hydrolyzed, and its diacetate prepared under the conditions of Experiment 2e. The yield of 1,6-dihydroxyanthraquinone (VIIf) was 89%, and the m.p. 281-282° (in a sealed capillary); the yield of 1,6-diacetoxyanthraquinone was 90%, and the m.p. 204-205° (from glacial AcOH) (cf. [13]). The dihydroxyanthraquinone and its diacetyl derivative obtained did not depress the melting points of 1,7-dihydroxyanthraquinone and its diacetate, synthesized from m-hydroxybenzoic acid [4].

3. Preparation of Glycols of Type (VIII). General Method.

A solution of 0.02 mole of adduct (II) in 10-15 times the amount of anhydrous benzene was gradually added with stirring at 5-7° to a solution of methylmagnesium iodide, prepared from 0.1 g-atm. of Mg, 0.105 mole of CH_3I and 25 ml of anhydrous ether. The reaction mixture was stirred without cooling for a further 3-5 hours, and decomposed by pouring into a stirred mixture of crushed ice and 125 ml of 1 N HCl [in the case of adducts (IIb) and (IIe), 125 ml of 1 N AcOH was used]. The aqueous solution was extracted with ether and ethyl acetate, the combined extract washed with water, 3-4 times with a 3% solution of $NaHCO_3$, and again with water, rapidly dried with Na_2SO_4, and evaporated to small volume in vacuum, and if crystallization did not begin spontaneously, the solution was cooled and rubbed with some solvent (usually ether).

a. 9,10-Dihydroxy-9,10-dimethyl-1,4,4a,9,9a,10-hexahydroanthracene (VIIIa) was obtained from adduct (IIa) [9] in the form of two stereoisomers. One of these, formed in 46% yield, had m.p. 124-125° (from benzene), λ_{max} 262 mμ (lg ϵ 2.32).

Found %: C 78.37; H 8.01; H_{act} 0.81. $C_{16}H_{20}O_2$.

Calculated %: C 78.65; H 8.25; $2H_{act}$ 0.82.

The second stereoisomer, formed in 22% yield, had m.p. 115-117° (from benzene) and λ_{max} 254 mμ (lg ϵ 2.51).

Found %: C 78.21; H 8.12. H_{act} 0.78. $C_{16}H_{20}O_2$.

Calculated %: C 78.65; H 8.25; $2H_{act}$ 0.82.

b. 2-Methoxy-9,10-dihydroxy-9,10-dimethyl-1,4,4a,9,9a,10-hexahydroanthracene (VIIIb) was obtained from adduct (IIb) in 40% yield.

M.p. 171-172° (from methanol), λ_{max} 237 and 262 mμ (lg ϵ 1.75 and 2.29).

Found %: C 74.50; H 8.12; H_{act} 0.55. $C_{17}H_{22}O_3$.

Calculated %: C 74.42; H 8.08; $2H_{act}$ 0.74.

c. 5-Methoxy-9,10-dihydroxy-9,10-dimethyl-1,4,4a,9,9a,10-hexahydroanthracene (VIIIc) was obtained from adduct (IIc) in 49% yield.

M.p. 139-140° (from 50% alcohol), λ_{max} 272 and 279 mμ (lg ϵ 3.22 and 3.22).

Found %: C 74.30; H 8.12; H_{act} 0.70. $C_{17}H_{22}O_3$.

Calculated %: C 74.42; H 8.08; $2H_{act}$ 0.74.

d. 3,5-Dimethoxy-9,10-dihydroxy-9,10-dimethyl-1,4,4a,9,9a,10-hexahydroanthracene (VIIId) was obtained from adduct (IId) in 56% yield.

M.p. 123-124° (from 25% alcohol), λ_{max} 276 and 283 mμ (lg ϵ 3.20 and 3.19).

Found %: C 70.99; H 7.80. $C_{18}H_{24}O_4$.

Calculated %: C 71.02; H 7.95.

4. Preparation of Ketols of Type (III) and (IX). General Method

To a stirred solution of 0.05 mole of adduct (II) in 10-15 times the amount of anhydrous benzene, cooled to 5-7°, was gradually added a solution of methylmagnesium iodide, prepared from 0.0625 g-at. of Mg, 0.065 mole of CH_3I, and 25 ml of anhydrous ether. The reaction mixture was stirred for a further 2-3 hours and treated as described in general method 3, but without the ethyl acetate extraction. In the preparation of ketols (IIId) and (IXb), the reaction was carried out in a stream of N_2, and the reaction solution worked up in an atmosphere of CO_2.

a. 10-Keto-9-hydroxy-9-methyl-1,4,4a,9,9a,10-hexahydroanthracene (IIIa) was obtained from adduct (IIa) in 70% yield).

M.p. 135-137° (from alcohol with charcoal), λ_{max} 248 and 291 mμ (lg ϵ 3.95 and 3.28).

Found %: C 79.24; H 6.76; H_{act} 0.47. $C_{15}H_{16}O_2$.

Calculated %: C 78.92; H 7.06; $1H_{act}$ 0.44.

During the purification of (IIIa), a small amount of 1,4-dihydroanthraquinone (VIa) with m.p. 208-210° (from ethyl acetate) (cf. [9]) was separated.

b. A mixture of 10-keto-3-methoxy- and 10-keto-2-methoxy-9-hydroxy-9-methyl-1,4,4a,9,9a,10-hexahydroanthracene (IIIb) and (IXa) was obtained from adduct (IIb) in the form of a red-brown uncrystallizable oil. After the usual treatment, only the residue of the original adduct precipitated from it. This oil was hydrolyzed as described in Experiment 6b, and the diketo alcohols (IVa) and (XIIIa) were isolated.

c. 10-Keto-5-methoxy-9-hydroxy-9-methyl-1,4,4a,9,9a,10-hexahydroanthracene (IIIc) was obtained from adduct (IIc) in 12% yield.

M.p. 194-196° (from 50% alcohol), λ_{max} 256 and 317 mμ (lg ϵ 3.86 and 3.68).

Found %: C 74.35; H 7.11; H_{act} 0.41. $C_{16}H_{18}O_3$.

Calculated %: C 74.39; H 7.02; $1H_{act}$ 0.39.

On prolonged standing, the mother liquor deposited crystals of 5-methoxy-1,4-dihydroanthraquinone (VIb), described in Experiment 2b.

d. 10-Keto-3,5-dimethoxy-9-hydroxy-9-methyl-1,4,4a,9,9a,10-hexahydroanthracene (IIId) was obtained from adduct (IId) in 14% yield. This compound usually began to crystallize even while its ether-benzene solution was being washed and dried (it was eluted from Na_2SO_4 with $CHCl_3$) and separated completely when the solution was evaporated to approximately $1/4$ of the initial volume.

M.p. 195-197° (from ethyl acetate), λ_{max} 254 and 318 mμ (lg ε 3.87 and 3.67).

Found %: C 71.09; H 6.78; H_{act} 0.33. $C_{17}H_{20}O_4$.

Calculated %: C 70.81; H 6.99; $1H_{act}$ 0.35.

Further evaporation of the solution yielded the isomeric 9-keto-3,5-dimethoxy-10-hydroxy-10-methyl-
-1,4,4a,9,9a,10-hexahydroanthracene (IXb). The yield was 54%.

M.p. 137.5-138.5° (from alcohol), λ_{max} 252 and 311 mμ (lg ε 3.88 and 3.44).

Found %: C 71.14; H 7.05; H_{act} 0.35. $C_{17}H_{20}O_4$.

Calculated %: C 70.81; H 6.99; $1H_{act}$ 0.35.

On prolonged standing, the evaporated solution deposited crystals of 3,5-dimethoxy-1,4-dihydroanthraquin-
one (VIc) with m.p. 172-173° (from alcohol).

Found %: C 70.91; H 5.12. $C_{16}H_{14}O_4$.

Calculated %: C 71.09; H 5.22.

5. Dehydration of Glycols (VIII) and Ketols (III) and (IX). General Method.

To 5 mmole of compound (III), (VIII) or (IX) in 10-30 times the amount of alcohol was added an equal
volume of conc. HCl and the mixture heated at 60° for 20-30 min in an atmosphere of N_2. On cooling, the pre-
cipitate of the dehydrated compound was collected by filtration and washed with water and alcohol.

a. 10-Hydroxy-9-methyl-1,4-dihydroanthracene (Xa) was obtained from ketol (IIIa) in 83% yield. The
m.p. was 117-119° (from petroleum ether); the substance readily changed during storage.

Found %: C 85.43; H 6.85; H_{act} 0.52. $C_{15}H_{14}O$.

Calculated %: C 85.68; H 6.71; $1H_{act}$ 0.48.

The acetyl derivative was obtained by means of $Ac_2O + H_2SO_4$; the yield was 80%, and the m.p. 153-156°
(from alcohol).

Found %: C 81.16; H 6.37. $C_{17}H_{16}O_2$.

Calculated %: C 80.92; H 6.39.

The methyl ether was obtained by means of Me_2SO_4 in 10% NaOH; the yield was 94%.

M.p. 97-99° (from alcohol), λ_{max} 236, 299 and 297 mμ (lg ε 4.65, 3.75, and 3.79).

Found %: C 85.64; H 7.16. $C_{16}H_{16}O$.

Calculated %: C 85.68; H 7.19.

b. 5-Methoxy-10-hydroxy-9-methyl-1,4-dihydroanthracene (Xb) was obtained from ketol (IIIc) in 96%
yield. The substance did not dissolve in 5% NaOH.

M.p. 115-116° (from heptane), λ_{max} 241, 311, 324, and 339 mμ (lg ε 4.60, 3.88, 3.91, and 3.93).

Found %: C 80.20; H 6.68; H_{act} 0.40. $C_{16}H_{16}O_2$.

Calculated %: C 79.97; H 6.71; $1H_{act}$ 0.42.

5-Methoxy-10-hydroxy-9-methyl-1,2,3,4-tetrahydroanthracene (XII) was obtained by hydrogenating 0.5 g
of (Xb) in 25 ml of anhydrous dioxane in the presence of 1 g of Raney nickel (20°, 1 atm). The yield was 97%.
The substance was insoluble in 5% NaOH.

M.p. 107.5-108° (from alcohol), λ_{max} 237, 312, 324, and 339 mμ (lg ε 4.55, 3.86, 3.89, and 3.90),
ν_{OH} 3425 cm^{-1} (8-methoxynaphthol-1 has ν_{OH} 3431 cm^{-1}).

Found %: C 79.33; H 7.55; H_{act} 0.40. $C_{16}H_{18}O_2$.

Calculated %: C 79.30; H 7.49; $1H_{act}$ 0.42.

<u>c.</u> 9,10-Dimethyl-1,4-dihydroanthracene (Xc) was obtained from glycol (VIIIa) in 99% yield.

M.p. 166-167° (from benzene), λ_{max} 238, 260, 285, and 297 mμ (lg ϵ 4.78, 3.53, 3.76, and 3.80).

Found %: C 92.52; H 7.63. $C_{16}H_{16}$.

Calculated %: C 92.26; H 7.74.

<u>d.</u> 5-Methoxy-9,10-dimethyl-1,4-dihydroanthracene (Xd) was obtained from glycol (VIIIc) in 90% yield.

M.p. 115-115.5° (from benzene), λ_{max} 241, 296, 306, 319, and 333 mμ (lg ϵ 4.59, 3.85, 3.92, 3.78, and 3.49).

Found %: C 85.21; H 7.66. $C_{17}H_{18}O$.

Calculated %: C 85.67; H 7.61.

<u>e.</u> 2-Keto-9,10-dimethyl-1,2,3,4-tetrahydroanthracene (XIa) was obtained from glycol (VIIIb) in 94% yield.

M.p. 120-121° (from benzene), λ_{max} 235 and 292 mμ (lg ϵ 4.89 and 3.79).

Found %: C 85.70; H 7.34. $C_{16}H_{16}O$.

Calculated %: C 85.68; H 7.19.

<u>f.</u> 3-Keto-5-methoxy-10-hydroxy-9-methyl-1,2,3,4-tetrahydroanthracenene (XIb) was obtained from ketol (IIId) in 93% yield. The substance was insoluble in 5% NaOH.

M.p. 138-140° (from 50% alcohol with $SnCl_2$), λ_{max} 237, 311, 324, and 339 mμ (lg ϵ 4.80, 3.85, 3.87, and 3.90), ν_{OH} 3423 cm^{-1} (cf. Exp. 5b).

Found %: C 74.87; H 6.32; H_{act} 0.49. $C_{16}H_{16}O_3$.

Calculated %: C 74.98; H 6.29; $1H_{act}$ 0.39.

<u>g.</u> 3-Keto-5-methoxy-9-hydroxy-10-methyl-1,2,3,4-tetrahydroanthracene (XIc) was obtained from ketol (IXb) in 95% yield.

M.p. 178-179° (in a sealed capillary) (from 50% alcohol with $SnCl_2$), λ_{max} 236, 309, 323, and 338 mμ (lg ϵ 4.85, 3.88, 3.86, and 3.81), ν_{OH} 3620 cm^{-1} (5-methoxynaphthol-1 has ν_{OH} 3605 cm^{-1}). The substance dissolved readily in 5% NaOH.

Found %: C 75.30; H 6.19; H_{act} 0.40. $C_{16}H_{16}O_3$.

Calculated %: C 74.98; H 6.29; $1H_{act}$ 0.39.

<u>h.</u> 3-Keto-5-methoxy-9,10-dimethyl-1,2,3,4-tetrahydroanthracene (XId) was obtained from glycol (VIIId) in 96% yield.

M.p. 95-96° (from alcohol), λ_{max} 239, 293, 306, 319, and 333 mμ (lg ϵ 4.72, 3.87, 3.91, 3.80, and 3.57).

Found %: C 80.52; H 6.96. $C_{17}H_{18}O_2$.

Calculated %: C 80.28; H 7.13.

6. Hydrolysis of Enol Ethers (II), (III), (VIII), and (IX). General Method.

A. A solution or a suspension of 1 g of the enol ether in 100 ml of ether was shaken with 50 ml of 0.3 N HCl for 5 hours at 20°. The ether layer was separated and the aqueous solution extracted exhaustively with chloroform. The combined extracts were washed with $NaHCO_3$ solution and water, dried over Na_2SO_4, and evaporated in vacuum.

B. To a solution of 1 g of enol ether in 50 ml of alcohol was added 25 ml of 0.1 N HCl [the hydrolysis of (IIId) required twice the amount of alcohol and 0.1 N HCl] and the mixture heated for 4 hours at 40°. The cooled solution was neutralized with a slight excess of $NaHCO_3$, evaporated to dryness in vacuum, and the dry residue extracted with hot ethyl acetate to give the ketone.

a. 2,9,10-Triketo-1,2,3,4,4a,9,9a,10-octahydroanthracene was obtained from adduct (IIb) by method A in 75% yield. The m.p. was 144-147° and the substance was unstable and changed during recrystallization.

Found %: C 73.82; H 5.48. $C_{14}H_{12}O_3$.

Calculated %: C 73.67; H 5.30.

b. 3,10-Diketo- and 2,10-diketo-9-hydroxy-9-methyl-1,2,3,4,4a,9,9a,10-octahydroanthracene (IVa) and (XIIIa) were obtained by Method B from the oily mixture of ketols (IIIb) and (IXa), described in Experiment 4b. The ethyl acetate extract was washed with a 3% KOH solution and water, dried with Na_2SO_4, and evaporated. The residue was dissolved in alcohol, decolorized with OU-B grade charcoal, the alcohol evaporated in vacuum, and the tars precipitated with ether; after concentration of the ether solution, one of the isomeric hydroxydiketones crystallized. The yield was 20%.

M.p. 134-135° (from benzene); λ_{max} 249 and 291 mμ (lg ϵ 3.63 and 3.09).

Found %: C 74.11; H 6.80. $C_{15}H_{16}O_3$.

Calculated %: C 73.75; H 6.60.

Semicarbazone: m.p. 217-219° with decomp. (from alcohol).

Found %: C 63.66; H 6.55; N 13.83. $C_{16}H_{19}O_3N_3$.

Calculated %: C 63.77; H 6.36; N 13.95.

The ether mother solution was evaporated, the residue dissolved in alcohol, and the semicarbazone of the second isomeric hydroxydiketone obtained by the usual method. The yield was 5% and the m.p. 237-239° (with decomp.) (from alcohol).

Found %: C 63.39; H 6.59; N 14.00. $C_{16}H_{19}O_3N_3$.

Calculated %: C 63.77; H 6.36; N 13.95.

0.3 g of this semicarbazone in 7 ml of glacial AcOH and 0.3 g of pyruvic acid in 9 ml of water were heated together at 70° for 1.5 hours, the solution diluted with water and extracted with ethyl acetate, and the extract washed, as described above. We obtained 0.20 g of the second hydroxydiketone with m.p. 120-121° (from benzene) and λ_{max} 250 and 291 mμ (lg ϵ 4.03 and 3.17).

Found %: C 73.58; H 6.62.

c. 3,10-Diketo-5-methoxy-9-hydroxy-9-methyl-1,2,3,4,4a,9,9a,10-octahydroanthracene (IVb) was obtained from ketol (IIId) by Method B in 75% yield.

M.p. 190-192° (in a sealed capillary) (from 50% alcohol), λ_{max} 256 and 319 mμ (lg ϵ 3.91 and 3.67).

Found %: C 70.18; H 6.86; H_{act} 0.41. $C_{16}H_{18}O_4$.

Calculated %: C 70.05; H 6.61; $1H_{act}$ 0.37.

d. 3,9-Diketo-5-methoxy-10-hydroxy-10-methyl-1,2,3,4,4a,9,9a,10-octahydroanthracene (XIIIb) was obtained from ketol (IXb) by Method B in 90% yield.

M.p. 159-161° (from 50% alcohol), λ_{max} 222, 255, and 313 mμ (lg ϵ 4.21, 3.91, and 3.51).

Found %: C 69.95; H 6.71; H_{act} 0.43. $C_{16}H_{18}O_4$.

Calculated %: C 70.05; H 6.61; $1H_{act}$ 0.37.

e. 2-Keto-9,10-dihydroxy-9,10-dimethyl-1,2,3,4,4a,9,9a,10-octahydroanthracene (XIVa) was obtained from glycol (VIIIb) by Method A in 55% yield [about 10% of the dehydrated ketone (XIa) was formed simultaneously]. When the reaction was carried out by Method B, part of the original enol ether could not be hydrolyzed; after recrystallization and a second hydrolysis of the substance remaining in the mother liquor, the total yield of dihydroxyketone (XIVa) was 78%.

M.p. 137-139° (from benzene), λ_{max} 221, 239, and 261 mμ (lg ϵ 2.15, 1.91, and 2.01).

Found %: C 73.86; H 8.01; H_{act} 0.79. $C_{16}H_{20}O_3$.

Calculated %: C 73.82; H 7.74; $2H_{act}$ 0.77.

<u>Semicarbazone:</u> m.p. 221-222° (with decomp.) (from alcohol).

Found %: C 64.22; H 7.20. $C_{17}H_{23}O_3N_3$.

Calculated %: C 64.33; H 7.30.

f. 3-Keto-5-methoxy-9,10-dihydroxy-9,10-dimethyl-1,2,3,4,4a,9,9a,10-octahydroanthracene (XIVb) was obtained from glycol (VIIId) by Method B in 62% yield.

M.p. 193-194° (from 50% alcohol), λ_{max} 218 and 278 mµ (lg ϵ 3.78 and 3.22).

Found %: C 70.36; H 7.70. $C_{17}H_{22}O_4$.

Calculated %: C 70.32; H 7.64.

SUMMARY

Starting from naphthaquinones, a synthesis was achieved of tricyclic compounds of type (XV), in which two rings are analogous structurally and sterically to rings D and C of natural tetracyclines. The presence in the third ring of type (XV) compounds of a reactive double bond, an enol-ether grouping or a carbonyl group offers the possibility of further introduction of substituents and then construction of the fourth ring of tetracyclines.

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EXOMOLECULAR INTERACTION AND COLOR

VIII. ABSORPTION SPECTRA OF MOLECULAR COMPLEXES OF 9-(p-DIMETHYLAMINO-STYRYL)-ACRIDINE WITH 10-ALKYL-9-METHYLACRIDINIUM SALTS

V. A. Izmail'skii and S. V. Dmitrienko

V. P. Potemkin Pedagogical Institute, Moscow
and Smolensk State Pedagogical Institute

An investigation of the spectra of molecular complexes from electron-donor (AK) and electronophilic (BK) components [1-5] led to the following conclusions.

a. The longwave maximum of molecular complexes of the type [AK + BK], where BK is a complex electronophilic chromophore, formed from a conjugated π-electron system (K), conjugated with a strong electronophilic chromophore B, for example NO_2 or $C = N^+$, and AK is a complex electron-donor chromophore, formed from K, conjugated with a strong electron-donor chromophore A, for example NMe_2, may lie extremely close to the maximum of the corresponding dye with the conjugated structure of the cochromophore [6] $B-K-A$, in which the systems BK and AK are superimposed one on the other. The λ_{max} of the complex may even be displaced bathochromically. Thus, for example, 429 mμ (in nitrobenzene) was found for (II), while only 396 mμ (in pyridine) [3] and 390 mμ (in alcohol) were found for (I).

(I) $O_2N-\langle\rangle-NMe_2$

$B-K-A$ λ_{max} 390 mμ in alcohol, 396 mμ in pyridine

(II) $\left[O_2N-\langle\rangle + \langle\rangle-NMe_2\right]$

[BK⌒AK] λ_{max} 429 mμ in nitrobenzene

(III) $\left[\langle\rangle\underset{Et}{N^+}-CH=CH-\langle\rangle-NMe_2\right]^+ J^-$

$B-K-A$ λ_{max} 525 mμ in MeOH, 491 mμ in water

(IV) $\left[\langle\rangle\underset{Et}{N^+}-CH=CH-\langle\rangle\right]^+ J^-$

(BK) λ_{max} 338 mμ in MeOH

(V) $\langle\rangle N-CH=CH-\langle\rangle-NMe_2$

(AK) λ_{max} 393 mμ

(VI) [(IV) + (V)] $BK + AK \rightleftarrows [BK \cap AK]$ λ_{max} 505 mμ in alcohol

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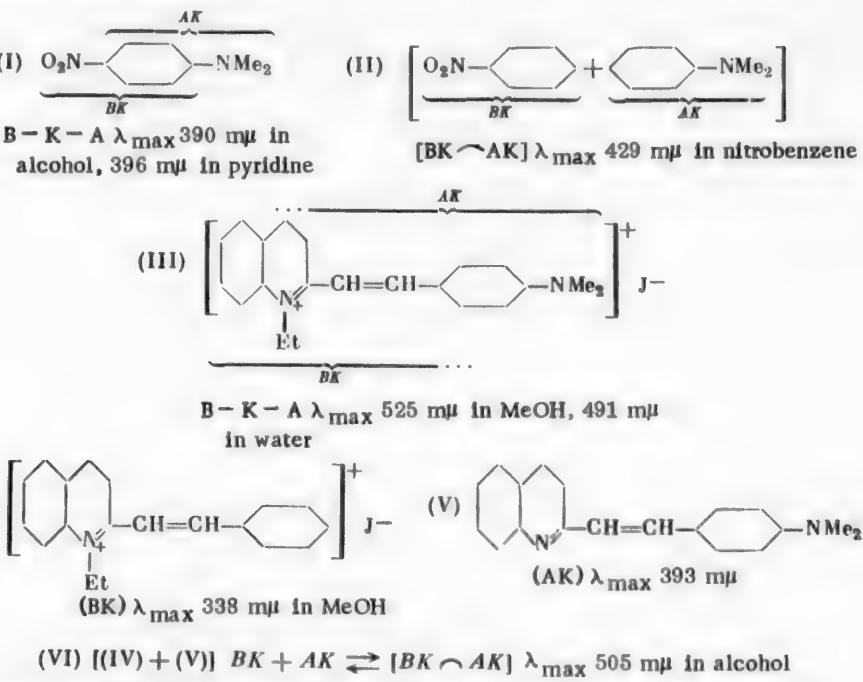
* The arc conjugation symbol ($\cap$) designates a partial π-bond, in this case an exo-ρ-bond [1].

For complex (VI) of 2-styrylquinolinium iodide (IV) with 2-(p-dimethylaminostyryl)-quinoline (V), a λ_{max} in alcohol of 505 mμ was found, while for the corresponding dye, 2-(p-dimethylaminostyryl)-quinolium iodide (III), λ_{max} was 525 mμ in methanol and 491 mμ in water [4b].

b. In a series of cases, complexes of the type [AK + BK] are more stable when the electron donor A and electronophilic B properties are intensified, and when the area of the cyclic conjugated π-electron system K is increased. Thus, the capacity for complex formation of quinoline derivatives is greater than that of pyridine derivatives [4,5]. On the basis of point b, one would expect that the stability of complexes formed from components with an acridine nucleus would be greater than that of those from components with a quinoline nucleus. A study of the spectra of complexes of type (X) from 10-ethyl-9-methylacridinium iodide (BK, VII) and 9-(p-dimethyl-aminostyryl)-acridine (AK, VIII) confirmed our hypothesis (Tables 1 and 2 and Figs. 1 and 2).
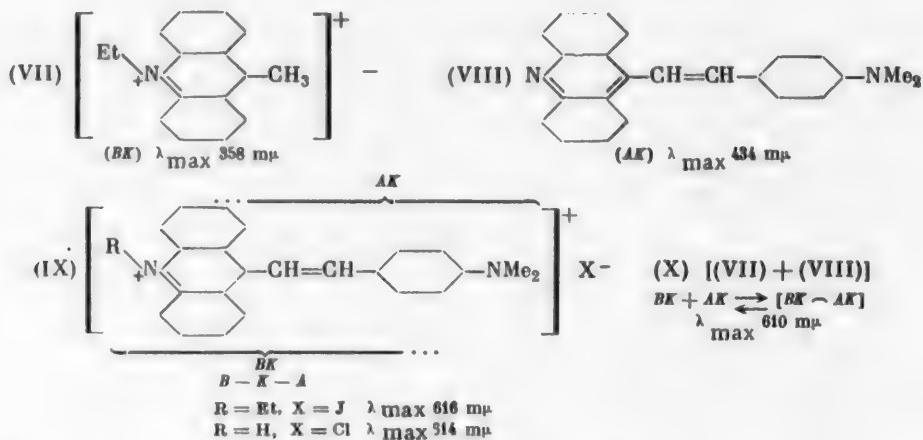
On the other hand, the observation made in point A was also confirmed; the longwave maximum of complex (X) (610 mμ) lies in the region of the maximum, corresponding to the dye with the conjugated B—K—A chromophore system (IX) (616 mμ).

The absorption maximum for the dye hydrochloride (IX, R = H, X = Cl) (Table 1, No. 8) was determined by a spectroscopic examination of a solution of AK (VII) in 0.01 N HCl in alcohol: (614 mμ, ϵ_{max} 29810). It almost coincides with λ_{max} 616 mμ for the ethiodide (IX, R = Et, X = I) (Table 1, Nos. 10 and 8). A fall in ϵ_{max} was observed for a solution of AK (VIII) in 0.1 N HCl in alcohol solution, and this may be due to the addition of HCl to the NMe$_2$ group also at high HCl concentrations (Table 1, No. 9).*

Solutions of the starting components were orange and light yellow in color (Table 1, Nos. 1 and 2, respectively). Solution No. 3, an equimolecular mixture of the components, was deep blue in color with c 10^{-3}, which indicated the formation of a complex (λ_{max} 610 mμ). At c 10^{-4}, the color became yellow-orange due to a displacement in the AK + BK ⇌ [AK⌢BK] equilibrium toward dissociation when the solution was diluted. At the same concentration, and with excess BK component (1AK:5BK) (Table 1, No. 4), the equilibrium was displaced toward the complex and the color again became bright blue, but not as bright as the color of solution No. 3 with c 10^{-3}. However, despite the excess BK component, on diluting solution No. 4 to 10^{-5}, the blue color and the complex maximum at 610 mμ disappeared and the maximum lay close to that calculated for the sum of the components (Nos. 6a and 20).

10-Benzyl-9-Me-acridinium chloride (Table 1, No. 11) has a lower capacity for forming the orange complex than methiodide (VII), although solution No. 12 at c 10^{-4} was dark green and had λ_{max} 610 mμ, but its ϵ_{max} was considerably smaller than the ϵ_{max} of solution No. 3, which indicates strong dissociation of the complex (Table 1, Nos. 11-13).

*A certain fall in ϵ_{max} and a considerable hypsochromic shift in λ_{max} (cf. Nos. 7 and 8) were observed for a solution of (VII) in glacial acetic acid (Table 1, No. 7), although the solution had a deep blue color. This was probably due not only to salt formation at the NMe$_2$ group, but also to dissociation of the acetate, as well.
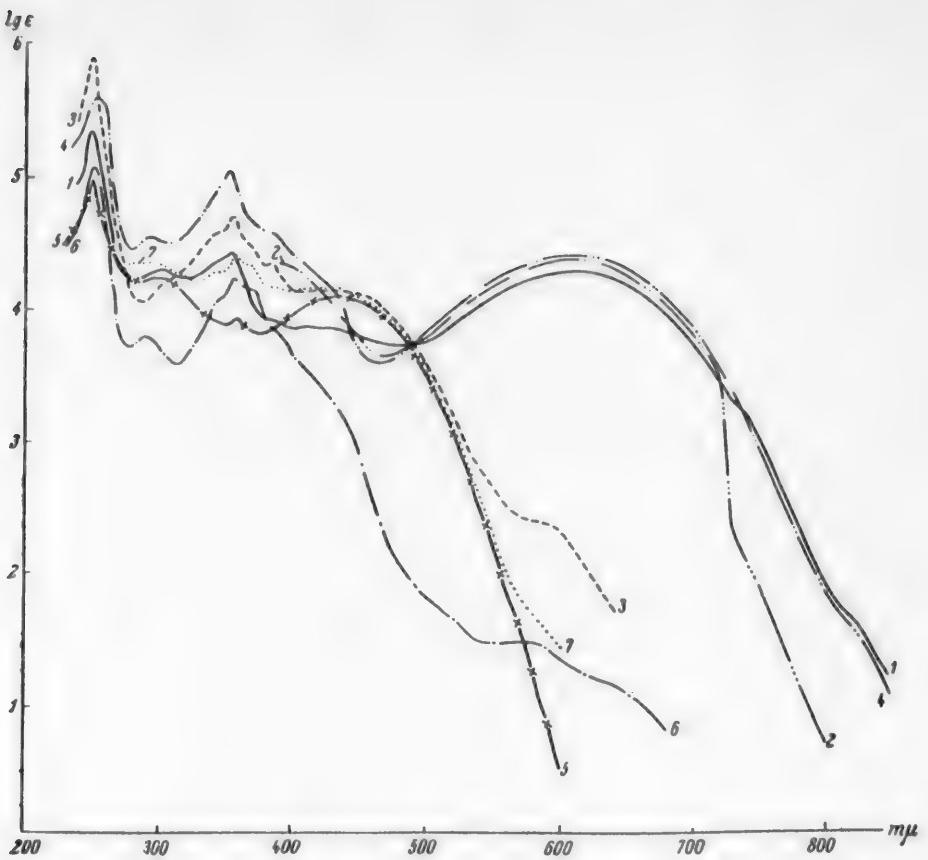
Fig. 1. (The numbers in brackets refer to Table 1.) 1) [9-(p-Me$_2$N-styryl)-acridine + (10-Et-9-Me-
-acridinium)] I, ratio of 1AK:1BK, 10^{-3} m (No. 3); 2) [9-(p-Me$_2$N-styryl)-acridine + (10-Et-9-Me-
-acridinium)] I, ratio of 1AK:5BK, 10^{-4} m (No. 4); 3) [9-(p-Me$_2$N-styryl)-acridine + (10-Et-9-Me-
-acridinium)] I, ratio of 1AK:5BK, 10^{-5} m (No. 5); 4) [9-(p-Me$_2$N-styryl)-acridine + (10-Et-9-Me-
-acridinium)] I, ratio of 1AK:5BK, 10^{-3} m ; 5) [9-(p-Me$_2$N-styryl)-acridine] in alcohol, 10^{-3} m
(No. 1); 6) [10-Et-9-Me-acridinium] I in alcohol, 10^{-3} m (No. 2); 7) [9-(p-Me$_2$N-styryl)-acri-
dine + (10-Et-9-Me-acridinium)] I, ratio of 1AK:1BK, 10^{-3} m calculated (No. 6).

The spectra of solutions of AK (VIII) and 10-ethyl-9-styrylacridinium iodide (BK) are compared in Table 2
and Fig. 2. We see that ϵ_{max} of solution No. 15 (Table 2) is slightly higher than that of No. 3 (Table 1). The
curve of 10-Et-9-styrylacridinium iodide has a band at λ_{max} 620 mμ with a very weak intensity (ϵ_{max}7). If it
is not caused by impurities in the preparation (as noted in Table 2 by brackets and question mark), then its ap-
pearance may be explained by the isomerization of the iodide to a pseudosalt and the formation of a complex of
the pseudosalt and acridinium iodide [5]. This problem will be examined in greater detail in another report.

If the styryl radical (9-C$_6$H$_5$CH=CH−) were introduced into the acridinium component BK instead of 9−CH$_3$,
one would expect an increase in the stability of the complex due to the increase in the π-electron system. How-
ever, the stability of the complex with 10-ethyl-9-styrylacridinium iodide in solution No. 17 (Table 2) was less
than that of No. 12, as can be seen from the position of λ_{max} (590 mμ) and the considerable decrease in ϵ_{max}
(only 3140) at $\underline{c}$ 10^{-4}. ϵ_{max} also fell in solution No. 16 at $\underline{c}$ 2.5 · 10^{-4}.

The surprising similarity of λ_{max} of the solutions of dye (IX) and of the [AK + BK] complex requires care
in connection with the conclusion in point $\underline{a}$ and necessitates consideration of other possible causes. First, the
problem arises as to whether the maximum at 610 mμ and the blue color in solutions Nos. 3 and 4 (Table 1) is
caused by alcoholysis of the acridinium salt (VII) [Acr]X + C$_2$H$_5$OH $\rightleftharpoons$ AcrOC$_2$H$_5$ + HX followed by the addition
of HX to p-dimethylaminostyrylacridine (VIII). However, this possibility should be rejected on the following
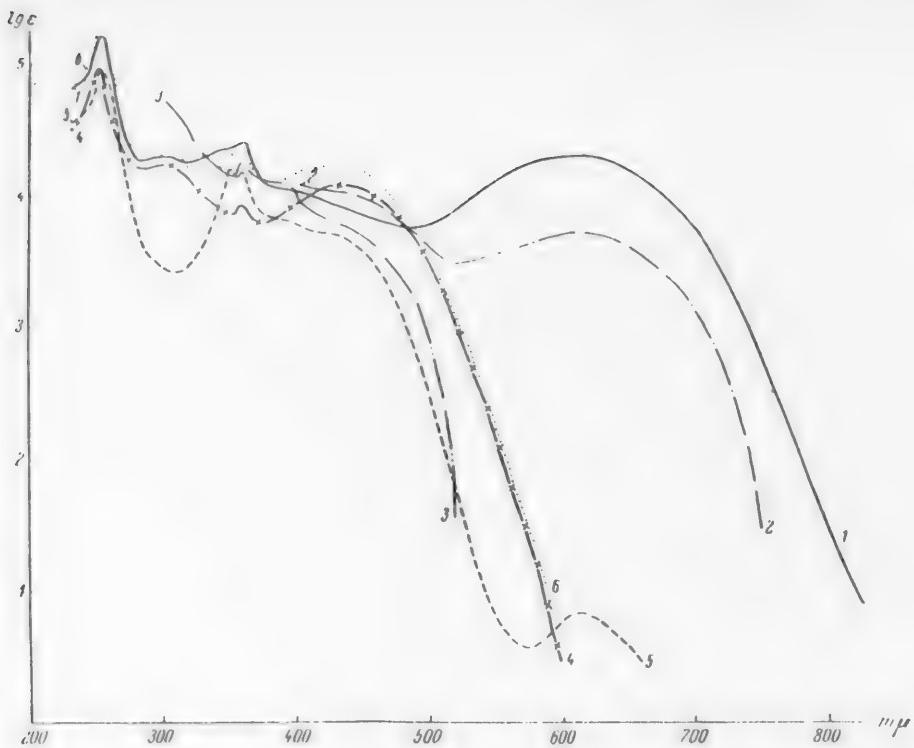
Fig. 2. (The numbers in brackets refer to Table 2.). 1) [9-(p-Me$_2$N-styryl)-acridine + (10-Et-9-
-styrylacridinium)] I, ratio of 1AK:1BK, 10^{-3} m (No. 15); 2) [9-(p-Me$_2$N-styryl)-acridine + (10-
-Et-9-styrylacridinium)] I, ratio of 1 AK:1BK, 2.5 · 10^{-4} m (No. 16); 3) [9-(p-Me$_2$N-styryl)- acri-
dine + (10-Et-9-styrylacridinium)] I, ratio of 1AK:1BK, 10^{-5} m (No. 18); 4) 9-(p-Me$_2$N-styryl)-
-acridine in alcohol, 10^{-3} m (No. 1); 5) [10-Et-9-styrylacridinium] I (No. 14); 6) 9-(p-Me$_2$N-
-styryl)-acridine + [(10-Et-9-styrylacridinium)] I, ratio of 1AK:1BK, 10^{-3} m calculated (No. 20).

grounds. (a) While the blue color of dye salts still remains when the salts are diluted, on dilution of solutions
Nos. 3 and 4, the blue, and even the green color, disappears at $\underline{c}$ 10^{-5}, even when there is a fivefold excess of
the BK component (1AK:5BK) (Table 1, No. 5, Fig. 1). (b) The blue color of solutions Nos. 3 and 4 disappears
even when several drops of water are added to the solution. (c) According to L. D. Vishnevskii's observations [5],
the band in the region of 600-616 mμ (λ_{max} 605 mμ) is present in the spectrum of solutions of acridinium salts
of (BK) with AK (VIII) as well as in carefully purified chloroform, when alcoholysis is impossible.* (d) Quinol-
inium salts are capable of forming colored solutions with diphenylamine [1,4,8] and with p-dimethylaminoacetanil-
ide [4a] as well, i.e., compounds which are incapable of forming halochromic salts. The complex of benzyl-
quinolinium chloride with diphenylamine was isolated even in the form of crystals [8, 4a]. According to P. A.
Solodkov's observations, the large ruby-red complex crystals are particularly readily isolated from amyl alcohol.

Secondly, another reason is also possible: the formation of orange halochromic salts from (VIII) could occur
as a result of peralkylation with transfer of the alkyl from the alkylacridinium salt (VII). However, a) the solu-
tions were prepared for spectroscopic examination by mixing in the cold, separately prepared solutions of AK and
BK components; the solution of the component mixture was examined spectroscopically as soon as possible after
preparation; b) alkyl exchange is also improbable, as both components are acridinic.

Thus, a new example confirms the fact established previously, that the excitation energy and absorption

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* N. A. Kitrosskii observed that analogous complexes were also formed in dichloroethane.

TABLE 1*

Solution No.	Structure	Component ratio (moles)	Concentration (M)	λ_{max}	$\Delta\lambda_{max}$ relative to No. 1	ϵ_{max}
1	9-(p-Me₂N-styryl)-acridine	(VIII) AK	10^{-3}	434	0	12500
2	10-Et-9-Me-acridinium I	(VII) BK	10^{-3}	358	—	16630
3	[$AK + BK$] (X)	$1AK : 1BK$	10^{-3}	610	+176	18680
4	[$AK + BK$] in excess of BK	$1AK : 5BK$	10^{-4}	610	+176	22860
5	[$AK + BK$] in excess of BK	$1AK : 5BK$	10^{-5}	~570 417	~+136 —17	~258 13750
6	[$AK + BK$] calc.	$1AK : 1BK$	10^{-3}	430	—4	14360
6a	[$AK + BK$] calc.	$1AK : 1BK$	10^{-4}	420	—	11500
7	9-(p-Me₂N-styryl)-acridine in glacial CH₃COOH	(VIII, R=H) X=CH₃COO⁻)	10^{-3}	588	+154	20820
8	9-(p-Me₂N-styryl)-acridine in 0.01 N HCl in EtOH	(VIII, R=H, X=Cl)	10^{-3}	614 356	+180 —	29810 20940
9	The same in 0.1 N HCl in EtOH	The same	10^{-3}	614 426 358	+180 — —	18700 7680 23960
10	10-Et-9-(p-Me₂N-styryl)-acridinium iodide	(IX, R = Et, X = I)	10^{-3}	616 442	+182	
11	10-Benzyl-9-Me-acridinium chloride	BK'	10^{-3}	386 352	— —	4750 18000
12	[$AK + BK'$]	$1AK : 1BK'$	10^{-4}	610 434	+176 —	8180 11500
13	($AK + BK'$) calc.	$1AK : 1BK'$	10^{-4}	420	—	12780

TABLE 2

Solution No.	Structure	Component ratio (moles)	Concentration (M)	λ_{max}	$\Delta\lambda_{max}$ rela. No.1	ϵ_{max}
1	9-(p-Me₂N-styryl)-acridine	(VIII) AK	10^{-3}	434	0	12500
14	10-Et-9-styryl-acridinium iodide	BK''	10^{-3}	(620)? 385 358		(7) 8820 15000
15	[$AK + BK''$]	$1AK : 1BK''$	10^{-3}	610	+176	20330
16	The same	$1AK : 1BK''$	$2.5 \cdot 10^{-4}$	610	+176	5550
17	" "	$1AK : 1BK''$	10^{-4}	590 360	+156	3140 26400
18	: :	$1AK : 1BK''$	10^{-5}	390		13210
19	: :	$1AK : 1BK''$	10^{-6}	370		6000
20	" " calc.	$1AK : 1BK''$	$2.5 \cdot 10^{-4}$	430 360		23530 24600

region, produced as a result of exomolecular interaction in complexes of the "donor—acceptor" type [BK + AK], may, in certain cases, lie very close to the excitation energy in conjugated compounds of the B—K—A type, i.e., in a conjugated system as a result of endomolecular interaction. The investigations have broadened our ideas on types of electron bonds. In 1939, Izmail'skii [2] had put forward the idea of a particular form of partial π-electron bond in the absence of a σ-bond (exo-bond).

Crystallochemistry has shown that association between molecules of similar complexes occurs through layer association between flat molecules, lying in parallel planes. The partial π-bond between molecules forms perpendicularly to the planes of the associated molecules. We imagine it as a force acting along the axis of the π-electron cloud function of the molecules, lying in parallel or almost parallel planes. It has been proposed that such a bond should be denoted as an "exo-ρ-bond" [1] in contrast to the exo-π-bond, which is found in benzene, for example, as a Dewar 1,4-bond or in anthracene as a 9,10-meso-bond [1]. A necessary condition for the formation of an exo-ρ-bond is a large difference in the extent of the electrophilic character* of the components forming the complex.

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* Me denotes CH₃ and Et, C₂H₅. All the solutions were in alcohol.

** The term "extent of electrophilic character" seems to us more appropriate than the term "extent of electronegative character," for a number of reasons.

EXPERIMENTAL

10-Ethyl-9-methylacridinium iodide (VII) was prepared from 9-methylacridine [9]. To a solution of 19.3 g (0.1 mole) of mesomethylacridine in 100 ml of alcohol was added 20 ml of ethyl iodide (about 30% excess). The mixture was boiled under reflux for 20 hours. The brick-red precipitate, which formed on cooling, was collected by filtration and washed with ether. After drying (80-100°), the yield was 20.1 g (43%). The filtrate was heated for 12 hours after the addition of 5 ml of ethyl iodide. On the following day, the precipitate was collected, washed, and dried; we obtained 5.9 g (12.6%). The total yield was about 55-56%. The product was recrystallized from alcohol. The orange-yellow crystals had m.p. 250-251°.

Found %: N 4.20. C$_{16}$H$_{16}$NI.

Calculated %: N 4.01.

10-Benzyl-9-methylacridinium chloride. To a solution of 9.65 g (0.05 mole) of mesomethylacridine in 100 ml of alcohol was added 8 ml (0.06 mole) of benzyl chloride. The mixture was heated on a water bath under reflux for 25 hours. After cooling in ice, the precipitate was collected by filtration, washed with ether, and dried at 100-110°. The yield was 6.7 g (m.p. 271-272°). The addition of 50 ml of ether to the filtrate yielded a further 1.9 g of product. The total yield was about 54%. After four recrystallizations from alcohol, the product was obtained as greenish yellow needles with m.p. 282°.

Found %: N 4.76. C$_{21}$H$_{18}$NCl.

Calculated %: N 4.38.

9-[p-Dimethylaminostyryl]-acridine (VIII). 7.72 g (0.04 mole of meso-methylacridine and 7.75 g (0.05 mole) of p-dimethylaminobenzaldehyde in acetic anhydride were boiled for 10 minutes under reflux. The mass, which thickened on cooling, was poured into a porcelain dish. Soda solution was added until the reaction was weakly alkaline. The precipitate was collected by filtration and washed with soda solution. The precipitate was heated with alcohol 4 times. On cooling, only a small amount of crystals (m.p. 244°) precipitated from the filtrates. The orange-yellow residue remaining after the fourth treatment with alcohol was dried in air and had m.p. 248°. The total yield was about 64%.

Found %: N 8.68. C$_{23}$H$_{20}$N$_2$.

Calculated %: N 8.64.

9-Styrylacridine and 10-ethyl-9-styrylacridinium iodide. These compounds were prepared by the method developed in our laboratory by P. A. Solodkov for the preparation of styryl derivatives from 2-methyl- and 4--methylquinoline. The method consisted of heating methylquinolines or mesomethylacridine with the azomethine obtained by the interaction of aniline with benzaldehyde (or, correspondingly, with p-dimethylaminobenzaldehyde) in acetic anhydride.

A solution of 3.86 g (0.02 mole) of mesomethylacridine and 4.70 g (0.025 mole) of benzalaniline in 7 ml of acetic anhydride was heated for 10 minutes at 138-155°. The cooled mass was poured into a beaker with cold water. A soda solution was added to an alkaline reaction to litmus. The pasty mass was heated to boiling with a solution of hydrochloric acid. The colorless precipitate of the hydrochloride formed was collected (m.p. 268 to 270°) and recrystallized from pyridine to give 9-styrylacridine with m.p. 175°. A further amount of styrylacridine could be isolated from the filtrate by addition of soda and recrystallization from pyridine (m.p. 175°). The yield was about 2.6 g (45.6%). The preparation was analyzed as the ethiodide.

9-Styrylacridine was heated in acetic anhydride with ethyl iodide in slight excess on a water bath under reflux for 3.5 hours. After the addition of alcohol, the mixture was heated for a further 1.5 hours. On cooling, the mixture deposited brick-red crystals of 10-ethyl-9-styrylacridinium iodide (Table 2, No. 14). The product was recrystallized from alcohol. It had m.p. 250°.

Found %: N 3.37. C$_{23}$H$_{20}$NI.

Calculated %: N 3.20.

10-Benzyl-9-styrylacridinium chloride (BSA) was obtained by the method of P. A. Solodkov by boiling 3.2 g of the chlorobenzylate of mesomethylacridine and 2.41 g of benzalaniline with 10 ml of acetic anhydride. After 2 minutes, the whole mass in the flask solidified. When it was cool, 10 ml of alcohol was added. The mass was boiled for about 1 hour. The precipitate was collected and washed with alcohol. After two recrystallizations from alcohol, the product had m.p. 270°. The yield was 3.5 g (86%).

In alcohol in the cold, BSA with 4-(p-dimethylaminostyryl)-quinoline gave a red-violet solution, which coincided with the color of a solution of 4-(p-dimethylaminostyryl)-quinoline hydrochloride. A solution of BSA with 2-(p-dimethylaminostyryl)-quinoline gave a color close to the color, but with a slight hypsochromic shift. With 9-(p-dimethylaminostyryl)-acridine, BSA gave a blue-green color, while the chlorobenzylate of mesomethyl-acridine with the same AK component [9-(p-dimethylaminostyryl)-acridine] gave a blue color.

10-Ethyl-9-(p-dimethylaminostyryl)-acridinium iodide (IX, R = Et, X = I). This substance was obtained by heating the ethiodide of mesomethylacridine with p-dimethylaminobenzaldehyde in acetic anhydride for 4 hours. The reaction did not proceed in an alcohol medium in the presence of piperidine. The product was recrystallized from alcohol. The m.p. was 310°.

SUMMARY

1. A study was made of the absorption spectra of alcohol solutions of 9-(p-dimethylaminostyryl)-acridine (electron-donor chromophoric AK component) with 10-ethyl- and 10-benzyl-9-methylacridinium and with 10-Et--9-styrylacridinium salts (electrophilic chromophoric BK component).

2. The formation of a new absorption region with λ_{max} at 610 mμ as a result of interaction of the components, we explained by the formation of a donor-acceptor complex. The maximum of the complex lay extremely close to λ_{max} 616 mμ, which corresponds to a dye with a conjugated chromophoric system of the B−K−A type. From a number of observations, the phenomenon of alcoholysis followed by addition of acid to the AK component or peralkylation must be rejected [for example, the disappearance of λ_{max} at 610 mμ on dilution of solutions, formation of a complex even in chloroform (L. D. Vishnevskii), in dichloroethane (N. A. Kitrosskii), etc.].

3. We put forward the hypothesis that complex formation is achieved as a result of layer association of flat molecules and a partial π-electron bond (exo-ρ-bond), which acts perpendicularly to the molecular plane, along the axis of the π-electron clouds.

4. As a result of the increased area of the cyclic conjugated systems, complexes from acridine components are more stable than those of quinoline and pyridine derivatives.

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REACTIVITY OF α-, β, AND γ-CHLOROALKYLSILANE CHLORIDES IN THE FRIEDEL-CRAFTS REACTION

E. A. Chernyshev and M. E. Dolgaya

Institute of Organic Chemistry, Academy of Sciences, USSR

By studying the Friedel-Crafts reaction with various α-, β-, and γ-chloroalkylsilane chlorides, we showed that there was a qualitative difference in the reactivity of these chlorides in this reaction [1]. It was found that chlorides with a chlorine atom in the β- and γ-positions relative to the silicon atom had a considerably higher activity than the α-chlorides; as a rule, replacement of a chlorine atom at the silicon in chloroalkyltrichlorosilanes by an alkyl radical raises the reactivity of the chloride (for example, $CH_3SiCl_2CH_2Cl$ is more active than Cl_3SiCH_2Cl).

In the present article, we report a quantitative comparison of the reactivities of the chlorides listed above in the Friedel-Crafts reaction. The reaction rate of each chloride was determined from the rate of hydrogen chloride liberation, and for this we used approximately the same procedure as was developed by Lebedev [2] for a kinetic study of the alkylation of aromatic compounds.

The experiments were carried out in a flask of 250 ml capacity, fitted with a stirrer with a seal, a reflux condenser, a thermometer, and a gas inlet tube through which dry nitrogen was passed through a bubbler into the reaction mixture at a constant rate of 30 liters/hour. This rate was found to be optimal, by experiment. At lower rates, the hydrogen chloride liberated was not flushed out completely by the nitrogen, and the results were inaccurate. The nitrogen was first passed through drying bottles with sulfuric acid and phosphorus pentoxide. Into the flask was placed 1 mole of benzene and 1.33 g (0.01 mole) of freshly sublimed aluminum chloride. The temperature of the reaction mixture was raised to 30° and 0.1 mole of the chloride investigated was injected. During the experiment, the temperature was maintained with an accuracy of ± 0.5°. The hydrogen chloride liberated was carried through the reflux condenser by the nitrogen and trapped by a titration solution of alkali. After every 10-30 sec, the amount of hydrogen chloride liberated was determined by back titration. As a rule, the reaction was complete in a few minutes.

It was found that for each of the given chlorides under the chosen reaction conditions, the amount of hydrogen chloride liberated in unit time was a certain constant (K mole/min.). An increase in the amount of catalyst led to an acceleration of the reaction. The experimental results are presented in Table 1, where benzene was taken as the aromatic compound in all experiments. Each constant is the average value from not less than three experiments, and the deviation did not exceed ± 5%.

An examination of the data obtained shows that the chloroalkylsilane chlorides with the chlorine atom in the α-position with respect to the silicon atom were the least reactive in the Friedel-Crafts reaction. The reaction rate with Cl_3SiCH_2Cl was found to be so small that it could not be determined at 30°. The reactivity of β-chloroalkylsilanechlorides was considerably higher than that of α-chlorides: in going from α- to β-chlorides, the reaction rate increased sharply by a factor of approximately 17-25. The reaction rates with γ-chloroalkylsilane chlorides, which were comparable with the reaction rates of the analogous β-chloroalkylsilane chlorides, were found to be higher or lower, depending on the number of chlorine atoms attached to the silicon atom. Thus, the reaction rate with γ-chloropropyltrichlorosilane was only 1.3 times higher than that with β-chloroethyltrichlorosilane. However, in the case of chloroalkylmethyldichlorosilanes, the opposite picture was observed: the reaction

TABLE 1

Chloroalkylsilane chloride	K at 30° (mole/min)
Cl_3SiCH_2Cl	$2.36 \cdot 10^{-4}$*
$Cl_3SiCH_2CH_2Cl$	$4.28 \cdot 10^{-3}$
$Cl_3SiCH_2CH_2CH_2Cl$	$5.48 \cdot 10^{-3}$
$CH_3SiCl_2CH_2Cl$	$3.67 \cdot 10^{-4}$
$CH_3SiCl_2CH_2CH_2Cl$	$4.47 \cdot 10^{-2}$
$C_2H_5SiCl_2CH_2CH_2Cl$	$4.17 \cdot 10^{-2}$
$CH_3SiCl_2CH_2CH_2CH_2Cl$	$6.72 \cdot 10^{-3}$
$Cl_3SiCHClCH_3$	$2.39 \cdot 10^{-4}$
$C_2H_5SiCl_2CHClCH_3$	$2.96 \cdot 10^{-4}$

TABLE 2

Chloroalkylsilane chloride	Aromatic compound	$K \cdot 10^{-3}$ at 30° (mole/min)
$Cl_3SiCH_2CH_2Cl$	C_6H_6	4.28
$Cl_3SiCH_2CH_2Cl$	C_6H_5Cl	1.67
$Cl_3SiCH_2CH_2Cl$	$C_6H_5CH_3$	5.95

rate was 6.5 times higher for β-chloroethylmethyldichlorosilane, $CH_3SiCl_2CH_2CH_2Cl$, than for γ-chloropropyl-methyldichlorosilane, $CH_3SiCl_2CH_2CH_2CH_2Cl$.

The introduction of an alkyl radical instead of a chlorine atom at the silicon atom, i.e., replacement of chloroalkyltrichlorosilane by chloroalkylalkyldichlorosilane, as a rule, led to an increase in the reaction rate by a factor of 1.2 to 2. β-Chlorides are an exception, as in the case of β-chloroethyltrichlorosilane and β-chloro-ethylalkyldichlorosilane, the reaction rate for the second was approximately 10 times higher, and the introduction of methyl or ethyl led to identical results.

The data obtained indicates the presence of a considerable negative induction effect (−I) in trichlorosilyl and alkyldichlorosilyl groups. These groups, which are electron accepting, decrease the capacity of the C−Cl bond for polarization, and make it more stable to the action of electrophilic reagents, for example, aluminum chloride. Naturally, the inductive effect of these groups has most influence on a C−Cl bond in the α-position with respect to the silicon. In going to β-chlorides, the action of the inductive effect falls sharply. Its effect on γ-chlorides is even weaker, but still exists, as is indicated by the fact that the introduction of an alkyl radical instead of a chlorine atom at the silicon ($Cl_3SiCH_2CH_2CH_2Cl$ and $CH_3SiCl_2CH_2CH_2CH_2Cl$) increases the reaction rate by a factor of 1.2. The higher reaction rate with chloroalkylalkyldichlorosilanes, as compared with chloro-alkyltrichlorosilanes indicates the stronger electron-accepting properties of the Cl_3Si group as compared with the RCl_2Si group. In addition, the results obtained lead to the conclusion that the reactivity of the C−Cl bond of β--chloroalkylalkyldichlorosilanes is not only affected by the induction effect of the RCl_2Si group, but also by the effect of conjugation of the Si−C bond with the C−Cl bond. Actually, according to the decrease in reactivity, the chloroalkyltrichlorosilanes may be arranged in the series γ > β > α, while the chloroalkylalkyldichlorosilanes are in the series β > γ > α. In the first case, the conjugation effect is almost absent, and the determining factor is practically only the induction effect, while in the second case, the conjugation effect is quite great and is superimposed on the induction effect. Consequently, replacement of one chlorine atom at the silicon in the Cl_3Si group by an alkyl radical leads to clear manifestation of the effect of conjugation of the Si−C bond with the C−Cl bond (Si and Cl atoms in the 1,4-position).

The rates of evolution of hydrogen chloride in the reaction of β-chloroethyltrichlorosilane with toluene and chlorobenzene were also determined. As was to be expected, the reaction rate with toluene was higher, and that with chlorobenzene lower than with benzene. The data obtained are presented in Table 2.

SUMMARY

1. From the rate of hydrogen chloride evolution, a comparative quantitative determination was made of the reactivities of α-, β-, and γ-chloroalkylsilane chlorides in the Friedel-Crafts reaction.

2. It was shown that the reactivity of the C—Cl bond of chloroalkylsilane chlorides was considerably affected by the negative induction effect (—I) of the Cl_3Si and RCl_2Si groups, with the effect of conjugation of the Si—C and C—Cl bonds superimposed on the induction effect in the case of β-chlorides.

3. The magnitude of the effect of conjugation of the Si—C and the C—Cl bonds in β-chlorides depends on the character of the radicals or atoms connected to the silicon, and decreases considerably when the alkyl radicals are replaced by chlorine atoms.

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SYNTHESIS OF 1,4-POLYISOPRENE USING ORGANOSODIUM COMPOUNDS AND TITANIUM TETRACHLORIDE

FORMATION OF HIGH-MELTING POLYMERS BY THE CATALYTIC POLYMERIZATION OF DIENES

E. N. Kropacheva, B. A. Dolgoplosk, V. F. Otten and K.G. Golodova

S. V. Lebedev All-Union Synthetic Rubber Research Institute

Original article submitted June 11, 1958

It is known that the polymerization of divinyl and isoprene by organosodium compounds forms polymers consisting mainly of 1,2 (for polydivinyl) and 3,4 and 1,2 (for polyisoprene) units. Polymers obtained by polymerization of divinyl on "Alfinov's catalyst" are exceptions, and contain up to 80% of 1,4 units [1].

The polymer of isoprene obtained with "Alfinov's catalyst" contains up to 70% of 1,4 units [2]. In recent years, it was shown possible to synthesize regularly formed polymers of divinyl and isoprene by using for the polymerization complexes formed by the interaction of alkylaluminums and titanium tetrachloride [3]. In the case of organosodium compounds, this type of complex has only been used for the polymerization of ethylene [4]. We showed that the complexes of organosodium compounds with titanium tetrachloride were also effective in the polymerization of dienes. The polymerization of isoprene in benzine solution at room temperature in the presence of isoamylsodium and titanium tetrachloride in equimolar amounts yielded two types of polymer: a benzine soluble elastomer and an insoluble amorphous powder. The same types of product were also formed in the polymerization of divinyl. With an increase in the ratio of titanium tetrachloride in the catalytic complex, the yield of the insoluble solid polymer increased. At an isoamylsodium-to-titanium tetrachloride ratio of 1:3, only solid polymer was formed (see Table 1). The total rate of the process increased noticeably with an increase in the catalyst concentration, the temperature, and the monomer concentration.

TABLE 1

Effect of Molar Ratio of Isoamylsodium-to-Titanium Tetrachloride on the Yield of the Soluble and Insoluble Parts of Polyisoprene. Isoamylsodium — 3.5 Weight % to Isoprene; Isoprene — 2.5 Weight % to Benzine

iso-C_5H Na: $TiCl_4$	Temp.	Time (hours)	Polymer yield (%)	
			insoluble solid polymer	soluble rubbery polymer
0 : 1	90°	4	0.9	0.5
1 : 3	90	4	29.2	0
1 : 2	90	4	12	3.6
1 : 1	90	4	10.6	35.2
2 : 1	70	12	2.9	23.8
4 : 1	70	12	0	41.5
1 : 0	50	2.5	0	75

TABLE 2

Structure of Soluble Polyisoprene, Obtained with an Equimolecular
Ratio of Isoamylsodium to Titanium Tetrachloride. Concentration
of Isoamylsodium 3.5 Weight % with Respect to Monomer; Con-
centration of Isoprene in Benzine 25 Weight %

Temp.	Structure from IR-spectral data. Amount of units (%)				Vitrification temperature of polymer
	1,2	3,4	trans-1,4	cis-1,4	
30°	5	6	69	20	—65°
30	2	5	23	70	—74
90	0	7	11	82	—
90	0	9	36	55	—69
90	3	5	56	36	—66
90	2	6	49	43	—
90	3	6	58	33	—70

Insoluble powdery polymers of divinyl and isoprene were also formed in small amounts by the polymeriza-
tion of isoprene and divinyl in benzine solution in the presence of titanium tetrachloride alone. Alkylaluminum
dichloride was particularly active in this respect. By studying the structures of the polymers obtained by means of
infrared spectroscopy, it was established that the benzine-soluble polyisoprene contained about 90% of units with
a 1,4 structure (see Table 2). This was the principal difference between the polymers we obtained and polyiso-
prene formed in the presence of sodium and organosodium compounds without the participation of titanium chlo-
rides. In the latter case, 3,4 and 1,2 units predominate in the chains.

It should be noted that the large variation in the ratio of 1,4-cis- and trans-units in the polyisoprene is ap-
parently connected with the inhomogeneity of the compositions of the complexes, obtained under the conditions
we chose for the reactions. The solid polybutadiene was a white, amorphous (according to x-ray structural analy-
sis data) powder, which did not dissolve in organic solvents. According to infrared spectroscopic data, the polymer
contained a certain amount of vinyl groups. This polymer softened and began to decompose at a temperature of
about 400°. The powdery polyisoprene (d 0.95) was also amorphous and did not dissolve in organic solvents. Ac-
cording to infrared data, it also contained a considerable amount of isopropenyl groups.

The powdery polymers obtained were extremely thermostable carbon-chain materials. Such a high soften-
ing point apparently may be caused only by the characteristics of the structure of the polymer chain itself. Cata-
lysts of the ionic type are capable of producing polymerization of olefins with internal and external double bonds.
In this connection, the reactions in polymers may develop in two directions.

1. A reaction may occur inside the chain, accompanied by the formation of condensed six-membered rings:

$$\sim CH_2-CH-CH_2-CH-CH_2-CH-CH_2\sim$$
$$\begin{array}{ccc} CH & CH & CH \\ \| & \| & \| \\ CH_2 & CH_2 & CH_2 \end{array} \qquad \xrightarrow{\text{Catalyst}}$$

$$\longrightarrow \begin{array}{c} CH_2 \quad CH_2 \quad CH_2 \quad CH_2 \\ \sim CH_2-CH \quad CH \quad CH \quad CH \quad CH\sim \\ \sim CH \quad CH \quad CH \quad CH \quad CH-CH_2\sim \\ CH_2 \quad CH_2 \quad CH_2 \quad CH_2 \end{array}$$
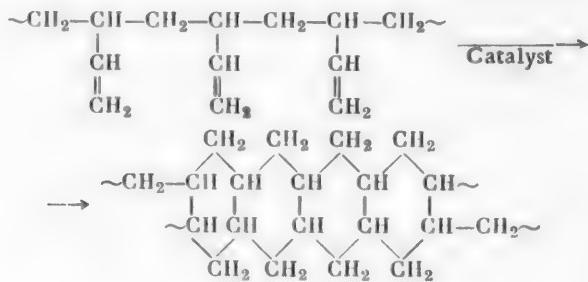
A reaction inside a chain containing internal double bonds leads to analogous results, for example, when a
solution of natural rubber is heated in the presence of alkylaluminum dichloride. In the case of unconjugated
dienes, reactions of this type lead to the formation of soluble polymers with isolated rings in the main chain, as
was shown in our laboratory on the example of the catalytic polymerization of dimethyldiallylsilane.

2. A reaction may occur between polymer chains, which must lead to structuralization of the polymers, due to the formation of cyclic structures of an indefinite character. Apparently, the latter cannot lead to such a high increase in the softening point of the substance.

High-melting products were isolated by Staudinger et al., in the thermopolymerization of cyclopentadiene [5]. From a determination of the unsaturation of the polycyclopentadiene, the author ascribed to the latter a structure with condensed, alternating five- and four-membered rings. The solubility and melting point of cyclopentadiene polymers changed sharply with an increase in the degree of polymerization. The pentamer had m.p. 270°. Products with a higher degree of polymerization melted at over 300° and decomposed at this temperature.

The high thermostability of the polymers synthesized is connected with their high melting point. The link between these effects was recently examined in one of our papers [6].

It should be noted that the formation of a high-melting cyclic polymer was observed also under conditions when organopotassium, magnesium, or aluminum compounds were used instead of organosodium compounds in a system containing excess $TiCl_4$.

EXPERIMENTAL

Starting materials and working procedure. Isoamylsodium (b.p. 105-110°), obtained by Morton's method [7], was used as a dispersion in benzine; $TiCl_4$ was used as a 10% solution in benzine. The benzine, isoprene, and divinyl were distilled over metallic sodium before use. All the work was done in an atmosphere of dry nitrogen, free from oxygen. The experiments were carried out in glass ampoules with continuous shaking. After the process, the reaction mixture was treated with alcohol. The rubber isolated was dried in vacuum. The insoluble part of the polymer was first washed with water. For each sample, we determined the infrared absorption spectrum on an IKS-11 spectrograph, the x-ray spectrum (for the insoluble, powdery polymers), and the vitrification point or the softening point by Marei's method [8].*

SUMMARY

1. It was shown that by means of complexes formed by the interaction of isoamylsodium and titanium tetrachloride, it was possible to obtain polyisoprene containing about 90% of 1,4-units in the chain.

2. It was shown that by the catalytic polymerization of butadiene and isoprene under certain conditions, it was possible to obtain solid thermostable polymers with high softening points.

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* The infrared spectra were plotted, and the microstructures of the samples estimated, by K. V. Nel'son, and the x-ray structural analysis carried out by S. L. Strunskii. The softening points were determined by A. I. Marei and M. Z. Al'tshuler.

* * Original Russian pagination. See C.B. translation.

* * * In Russian.

INVESTIGATION IN THE FIELD OF SYNTHESIS AND TRANSFORMATIONS IN THE DIARYLUREA SERIES.

VIII. THE SYNTHESIS OF CHLORINE-SUBSTITUTED DIARYLUREAS

D. F. Kutepov, A. A. Potashnik and K. I. Vavilina

Original article submitted May 12, 1958

In the literature, a number of methods are cited for the preparation of diarylureas substituted in the ring, starting with the appropriate aryl amines and phosgene [1]. In addition, it has been shown that reactions of this type proceed best under homogeneous conditions. Most frequently, nitrobenzene and toluene have been used as solvents for this purpose.
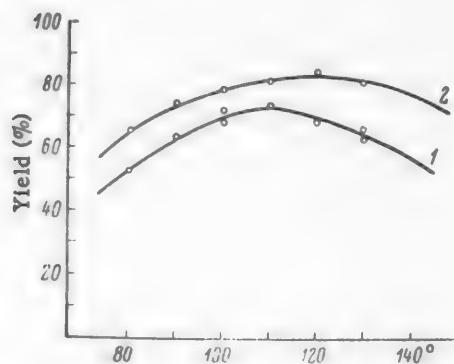
Effect of temperature on yield of hexachlorodiphenyl-urea from phosgenation of 2,4,6-trichloroaniline: 1) in chlorobenzene; 2) in trichlorobenzene.

In our previous communication [2], we described methods for the preparation of chlorine-substituted diarylureas under various conditions. When the hydrogen atoms of the amino group were highly labile, the reaction proceeded rather vigorously at room temperature. Thus, for example, 2,4,5-tri-chloroaniline and 2,4-dichloroaniline were phos-genated satisfactorily at 20-65° in dichloroethane medium. Moreover, the purity of the products and the yields were increased considerably when the hydrogen chloride formed was removed from the field of reaction [3]. In comparison with the products mentioned, the phosgenation of 2,4,6-trichloro- and 2,3,5,6-tetrachloroaniline took place only at high temperature in solution in high-boiling solvents.

In the present work, we have investigated the phosgenation of 2,4,6-trichloroaniline in chloroben-zene and 1,2,4-trichlorobenzene. It has been shown that at an elevated temperature the reaction of the trichloroaniline with phosgene goes better in trichlorobenzene with all other conditions being the same. It also has been established that with an increase in temperature, the reaction rate and the yield of the final product gradually reach their optimum, and with further increase in tempera-ture they begin to diminish. It is apparent that, at an elevated temperature, side reactions become significant, leading to partial, and even complete decomposition of the hexachlorodiphenylurea formed. Comparative data on the preparation of hexachlorodiphenylurca (see figure) show that in trichlorobenzene the yield of the former is somewhat higher than in chlorobenzene medium. The optimum temperature for the reaction in trichlorobenzene is 120° (in chlorobenzene, 110°).

EXPERIMENTAL

1. Phosgenation of 2,4-Dichloroaniline in Dichloroethane Medium

In a reactor provided with a stirrer, thermometer, manometer, and reflux condenser, were placed 20 g of

2,4-dichloroaniline, 80 ml of dichloroethane, 80 ml of water, and 2 drops of OP-7 emulsifier. 16 g of sodium carbonate was introduced into the reaction mixture in 3 portions; 12.2 g of phosgene (200%) was passed through in the course of 50 minutes. The reaction was carried out at room temperature. After the phosgene was passed through, the reaction mixture was stirred at 20° for 3 hours, then for 30 minutes more at 65°. After this, the reaction mixture was kept without stirring for 1 hour. The precipitate that had separated out was filtered off, washed with water and with dichloroethane, and dried at room temperature. 18.7 g (86.57% of 2,2',4,4'-tetrachlorodiphenylurea was obtained with m.p. 272.5-273° (according to the literature data, 273°). After separation of the precipitate, the filtrate was used for the phosgenation of a new portion of 2,4-dichloroaniline, which brought the total yield of tetrachlorodiphenylurea much closer to quantitative.

2. Phosgenation of 2,4,6-Trichloroaniline in Chlorobenzene Medium

In a reactor were placed 10 g of trichloroaniline and 50 ml of chlorobenzene. The reaction mixture was heated while being stirred, and was kept at the assigned temperature for 30 minutes. During this time, the trichloroaniline dissolved in the chlorobenzene. Then, over the course of 1.5 hours, 150% of the theoretical amount of phosgene was bubbled in through a bottle containing sulfuric acid. After the passage of the phosgene was completed, the reaction mixture was kept at the same temperature while being stirred for 2.5 hours more. Thus, the total duration of the phosgenation reaction was 4 hours. The white precipitate that separated out after cooling was filtered off, washed three times with chlorobenzene (20 ml portions), and twice with alcohol (20 ml portions). The filtered precipitate was dried at 98-100°. 2,2',4,4',6,6'-Hexachlorodiphenylurea was obtained, which contained no tetrachloro derivative according to the results of analysis. The experimental results are given in the table (10 g of trichloroaniline was used in all experiments).

Reaction temperature	Yield of hexachlorodiphenylurea (in %)	
	in chlorobenzene solution	in chlorobenzene solution
80°	52.23	65.20
90	64.54	72.70
100	68.95	72.93
110	73.85	81.61
120	69.42	83.72
130	65.50	81.95
140	—	80.00

3. Phosgenation of 2,4,6-Trichloroaniline in Trichlorobenzene Medium

The experiments were carried out in the same way as those in chlorobenzene solution. The same temperature regime was maintained, and the same amounts of starting materials were used. The results are given in the table.

4. Phosgenation of 2,3,5,6-Tetrachloroaniline in Nitrobenzene Medium

10 g of tetrachloroaniline and 30 ml of nitrobenzene were introduced into the reactor. The mixture was heated to 130°, during which all the tetrachloroaniline went into solution. Then a strong current of phosgene (with a considerable excess) was passed through the reaction solution for 1.5 hours; during this time, a white precipitate of 2,2',3,3',5,5',6,6'-octachlorodiphenylurea separated out, which was filtered off and washed several times with acetone and ether. M.p. 347° (with decomp.). Octachlorodiphenylurea is not described in the literature.

Found %: N 5.84; 5.69; Cl 60.33; 58.82. $C_{13}H_4ON_2Cl_8$.

Calculated %: N 5.74; Cl 58.02.

SUMMARY

1. The phosgenation of 2,4,6-trichloroaniline and 2,4-dichloroaniline in high-boiling solvents has been investigated. It has been established that the preparation of 2,2',4,4',6,6'-hexachlorodiphenylurea in trichlorobenzene proceeds with a good yield.

2. 2,2',3,3',5,5',6,6'-Octachlorodiphenylurea, which is not described in the literature, has been synthesized.

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ACETYLENIC AMINOALCOHOLS AND THEIR ESTERS

I. N. Nazarov, R. I. Kruglikova and G. M. Nikolaev

Original article submitted March 21, 1958

In order to further investigate the relationship of the physiological activity of the esters of alkanolamines to their structure, we undertook the synthesis of a number of esters of tertiary butanolamines, both saturated and containing multiple bonds in the alcohol chain.

$$>\text{C—C} \equiv \text{C—CH}_2\text{N} < \qquad >\text{C—CH} = \text{CH—CH}_2\text{N} < \qquad >\text{C(CH}_2)_3\text{N} <$$
$$\overset{\text{OCOAr}}{|} \qquad\qquad \overset{\text{OCOAr}}{|} \qquad\qquad \overset{\text{OCOAr}}{|}$$
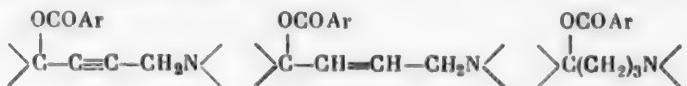
A method recently described for the preparation of acetylenic aminoalcohols and butanolamines by the condensation of acetylenic amines with ketones in the presence of various condensing agents, with subsequent reduction of the acetylenic aminoalcohols, in most instances gives low yields [1]. The synthesis of substituted butanolamines, in particular 5-diethylaminopentanol-2, which is used as an intermediate for the preparation of atabrine, plasmoquine, and a number of other compounds, is carried out with good yields on the basis of acetoacetic ester, which naturally limits the substitution on the carbon linked with the hydroxyl group.
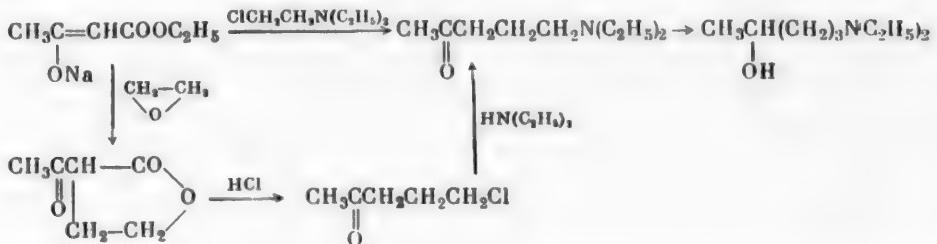
For the preparation of various aminobutanols, and also aminobutynols and aminobutenols and their esters, we used a simpler general method of synthesis that comprises carrying out the Mannich reaction with the appropriate esters of the acetylenic alcohols and subsequent hydrogenation of the acetylenic amino esters. Saponification of the acetylenic amino esters followed by selective hydrogenation makes it possible to prepare the corresponding acetylenic, ethylenic, and saturated aminoalcohols.

↓

$$R_2'C(OCOR'')-CH=CH-CH_2NR_2'''$$

↓

$$R_2'C(OH)-CH=CH-CH_2NR_2'''$$

↓

$$R_2'C(OCOR'')-CH_2CH_2CH_2NR_2'''$$

↓

$$R_2'C(OH)-CH_2CH_2CH_2NR_2'''$$
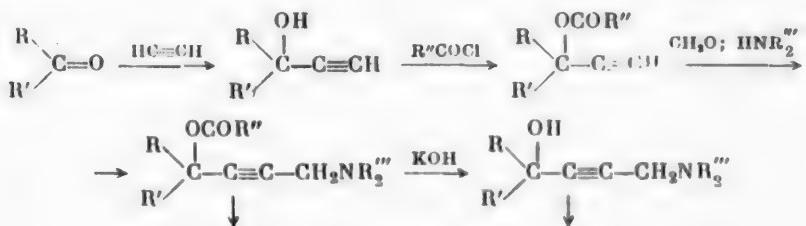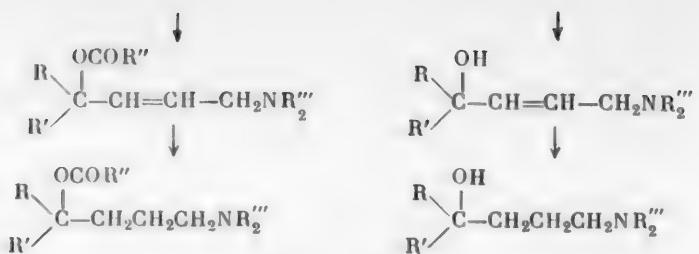
We prepared acetylenic alcohols by the reaction of acetylene with ketones at 5–7 atm pressure in the presence of powdered potassium hydroxide [2]. The ketones used were acetone, methyl ethyl ketone, cyclohexanone, and cyclopentanone.

The Mannich reaction goes with acetylene itself only in the presence of copper acetylide, and results in the formation of propargylamine and, to a lesser extent, of the corresponding 1,4-diaminobutyne [3]. In the case of phenyl- [4] and vinylacetylenes [5], this reaction proceeds with good yields even without a catalyst. The same is true of the alkylacetylenes. When the Mannich reaction is carried out with α-acetylenic alcohols, as has been shown, the desired aminoalcohols are obtained in slight yields [6], while with β-acetylenic alcohols this reaction gives a 60% yield [7]. The Mannich reaction can be carried out with good yields with both ethers and esters of the α-acetylenic alcohols. This anomalous behavior of the α-acetylenic alcohols has not yet been explained. The acetylenic alcohols were therefore first esterified. The esterification was carried out with benzoyl chloride and phenoxyacetyl chloride, the radicals of which should be contained in the final products, and with acetic anhydride; from the acetates we obtained the corresponding aminoalcohols, by saponification. Esterification with benzoyl chloride and phenoxyacetyl chloride by the methods of Spasov and of Schotten and Baumann did not give satisfactory results. The esters were obtained in good yields by the reaction of the appropriate acetylenic alcohols with benzoyl chloride and phenoxyacetyl chloride in the presence of dry pyridine. Experiments were carried out in which the pyridine was used in fivefold excess and served simultaneously as the solvent; in other experiments, the solvent was benzene, and the pyridine and acid chloride were used in equimolecular amounts. In the latter case, the process was simpler and the yields of the esters were higher.*

The acetates of the acetylenic alcohols listed are formed in good yields by the reaction with the alcohols of acetic anhydride in the presence of a few drops of sulfuric acid. The Mannich reaction was carried out by heating the appropriate acetylenic ester for 25–40 hours with paraform and piperidine or diethylamine in dioxane solution. The time of heating depended on the amount of the starting materials. Thus, when the reaction was carried out with 10 g of dimethylethynylcarbinol benzoate, the corresponding base was obtained in 83% yield after 12 hours of heating. When the same experiment was carried out with 85 g of the alcohol benzoate, a 48% yield of the base was obtained after 39 hours heating, and 30 g of the starting benzoate was recovered. The Mannich reaction goes more easily with the acetates, somewhat more difficultly with the benzoates, and especially so with the phenoxyacetates of the alcohols.

The acetates of the acetylenic aminoalcohols were saponified by heating them for 1 hour in an alcoholic solution of potassium hydroxide, and 80–90% yields of the corresponding aminoalcohols were obtained. The saponification of the benzoates proceeded similarly. The results of reduction of the acetylenic aminoalcohols and their esters will be reported later.

EXPERIMENTAL

1-Ethynylcyclohexanol-1 Acetate (VII) [9]

5 drops of concentrated sulfuric acid was added to 82 g (0.80 mole) of acetic anhydride, and while the mixture was stirred and cooled with ice water, 100 ml of 1-ethynylcyclohexanol-1 was slowly run in at such a rate that the temperature of the mixture did not rise above 20°. After 30 minutes, the reaction mixture was diluted.

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*After our work was finished, a short communication appeared on the possibility of preparing the benzoates of tertiary acetylenic alcohols in good yields by the reaction of 1 mole of benzoic acid, 1 mole of alcohol, and 1.5–2 moles of benzene- or toluenesulfonyl chloride in anhydrous pyridine [8].

TABLE 1

Esters of Acetylenic Alcohols $R\diagdown\diagup\!\!\!\!\!\underset{R'}{\overset{OCOR''}{C}}\!-\!C\equiv CH$

Comp. No.	$R\diagdown\diagup R'\ C-$	R″	Boiling point (pressure in mm)	Melting point	n_D^{20}	d_D^{20}	Yield (%)	Found (%) C	Found (%) H	Empirical formula	Calc. (%) C	Calc. (%) H
(I)	$(CH_3)_2C-$	CH_3	130—132° (760)	—	1.4200	0.9325	72	—	—	$C_7H_{10}O_2$	—	—
(II)	$(CH_3)_2C-$	C_6H_5	78—80 (2)	—	1.5101	1.0383	68	76.55, 76.77	6.37, 6.30	$C_{12}H_{12}O_2$	76.59	6.37
(III)	$(CH_3)_2C-$	$CH_2OC_6H_5$	128—131 (3.5)	80—81.5°	—	—	56	71.83, 71.75	6.68, 6.71	$C_{13}H_{14}O_3$	71.56	6.42
(IV)	$\underset{CH_3}{\overset{C_2H_5}{C}}-$	CH_3	70—71 (37)	—	1.4274	0.9310	80	—	—	$C_8H_{12}O_2$	—	—
(V)	$\underset{CH_3}{\overset{C_2H_5}{C}}-$	C_6H_5	92 (2.5)	—	1.5106	1.0255	61	77.36, 77.35	6.96, 6.72	$C_{13}H_{14}O_2$	77.22	6.93
(VI)	$\underset{CH_3}{\overset{C_2H_5}{C}}-$	$CH_2OC_6H_5$	125—127 (2.5)	50.5—52	—	—	37	72.43, 72.43	6.85, 6.97	$C_{14}H_{16}O_3$	72.46	6.81
(VII)	(cyclohexyl)	CH_3	104—105 (22)	—	1.4660	—	90	—	—	$C_{10}H_{14}O_2$	—	—
(VIII)	(cyclohexyl)	C_6H_5	140—142 (3.5)	54—55	—	—	78	79.09, 78.69	7.17, 7.14	$C_{15}H_{16}O_2$	78.94	7.03
(IX)	(cyclopentyl)	CH_3	74—75 (16)	—	1.4601	—	75	—	—	$C_9H_{12}O_2$	—	—
(X)	(cyclopentyl)	C_6H_5	120—122 (2)	59.5—61	—	—	83	78.67, 78.69	6.82, 6.85	$C_{14}H_{14}O_2$	78.89	6.54

TABLE 2

Esters of Acetylenic Aminoalcohols $\begin{matrix} R \\ {} \\ R' \end{matrix}\!\!>\!\!\overset{OCOR''}{\underset{}{C}}\!\!-\!\!C\!\equiv\!C-CH_2NR'''_2$
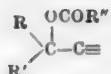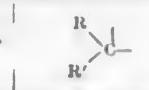
Compd. No.	$\begin{matrix}R\\ \backslash\\ C\\ /\\ R'\end{matrix}$	R"	NR'''_2	Boiling point (pressure in mm)	n_D^{20}	d_{20}^{20}
(XI)	$(CH_3)_2C-$	CH_3	NC_5H_{10}	123—125° (3.7)	1.4728	0.9800
(XII)	$(CH_3)_2C-$	C_6H_5	NC_5H_{10}	178—180 (3.5)	1.5232	1.0432
(XIII)	$(CH_3)_2C-$	C_6H_5	$N(C_2H_5)_2$	141 (3)	1.5050	0.9940
(XIV)	$(CH_3)_2C-$	$CH_2OC_6H_5$	$N(C_2H_5)_2$	158—160 (2)	1.5045	1.0340
(XV)	$\begin{matrix}CH_3\\ \backslash\\ C-\\ /\\ C_2H_5\end{matrix}$	CH_3	NC_5H_{10}	102—104 (2.5)	1.4739	0.9703
(XVI)	$\begin{matrix}CH_3\\ \backslash\\ C-\\ /\\ C_2H_5\end{matrix}$	C_6H_5	NC_5H_{10}	178—180 (3)	1.5238	—
(XVII)	$\begin{matrix}CH_3\\ \backslash\\ C-\\ /\\ C_2H_5\end{matrix}$	C_6H_5	$N(C_2H_5)_2$	157—158 (3)	1.5055	0.8898
(XVIII)	$\begin{matrix}CH_3\\ \backslash\\ C-\\ /\\ C_2H_5\end{matrix}$	$CH_2OC_6H_5$	$N(C_2H_5)_2$	160—161 (2)	1.5010	1.0232
(XIX)	(cyclohexyl)	CH_3	NC_5H_{10}	145—146 (2)	1.4963	1.0140
(XX)	(cyclohexyl)	CH_3	$N(C_2H_5)_2$	110—111 (2)	1.4757	0.9690
(XXI)	(cyclohexyl)	C_6H_5	NC_5H_{10}	190—192 (2.5)	1.5398	—
(XXII)	(cyclohexyl)	C_6H_5	$N(C_2H_5)_2$	171—172 (2.5)	1.5235	1.028
(XXIII)	(cyclopentyl)	CH_3	NC_5H_{10}	158—160 (3)	1.4965	—
(XXIV)	(cyclopentyl)	C_6H_5	NC_5H_{10}	178—180 (2.5)	1.5422	1.071
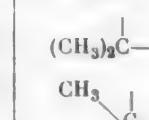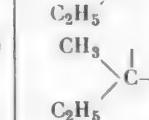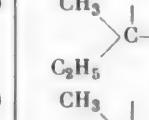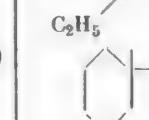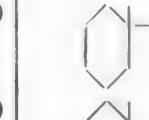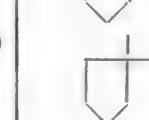
Yield (%)		Melting point of derivatives (solvent)	Found % N	Empirical formula	Calc. % N
on material used	on material reacted				
61	74	Methiodide 106-108° (acetone-alcohol)	6.44, 6.50	$C_{13}H_{21}O_2N$	6.28
78	83	Methiodide 170-171° (acetone) Hydrochloride 136-137.5° (acetone)	4.79, 5.12	$C_{18}H_{29}O_2N$	4.91
83.5	83.5	Methiodide 160-161° (alcohol) Picrate 96.5-98° (alcohol).	5.21, 5.24	$C_{17}H_{29}O_2N$	5.14
68	75	—	4.76, 4.84	$C_{18}H_{25}O_3N$	4.65
65	87	Hydrochloride 129-131° (alcohol) Picrate 115-116° (alcohol)	5.94, 6.07	$C_{14}H_{23}O_2N$	5.90
37	—	Methiodide 136.5-137.5° (acetone) Hydrochloride 137.5-139° (acetone	4.97, 4.83	$C_{19}H_{25}O_2N$	4.68
74	82	Methiodide 130-131.5° (alcohol)	5.16, 5.08	$C_{18}H_{25}O_2N$	4.89
54	68	—	5.50, 4.70	$C_{19}H_{27}O_3N$	4.42
56	66	Methiodide 153-154° (alcohol-ether) Hydrochloride 152-153° (acetone)	5.64, 5.58	$C_{16}H_{25}O_2N$	5.32
88	96	—	5.80, 5.88	$C_{15}H_{25}O_2N$	5.58
85	85	Methiodide 175-176° (acetone) Hydrochloride 182.5-184° (acetone)	4.50, 4.62	$C_{21}H_{27}O_2N$	4.31
87	98	Methiodide 150-151° (acetone) Hydrochloride 137-138° (acetone)	4.81, 4.52	$C_{20}H_{27}O_2N$	4.48
60	72	Hydrochloride 215-216° (acetone-alcohol) Picrate 98-99° (acetone)	5.63, 5.80	$C_{15}H_{23}O_2N$	5.62
30	49	Methiodide 194-195° (acetone) Hydrochloride 180-181° (acetone-alcohol)	4.49, 4.49	$C_{20}H_{25}O_2N$	4.51

TABLE 3

Acetylenic Aminoalcohols

$$\underset{R'}{\overset{R}{\diagup}}\overset{OH}{\underset{|}{C}}{-}C{\equiv}C{-}CH_2NR_2'''$$

Compound No.	$\dfrac{R}{R'}{>}C{-}$	NR_2'''	Boiling point (pressure, in mm)	n_D^{20}	d_{20}^{20}	Yield (%)	Melting point of derivatives (solvent)	Found % N	Empirical formula	Calc. % N
(XXV)	$(CH_3)_2C{-}$	NC_5H_{10}	120° (4.5)	1.4908	0.9465	78	Hydrochloride 213.5–214° (alcohol) Methiodide 137–139° (alcohol)	7.77, 8.05	$C_{11}H_{19}ON$	7.74
(XXVI)	$\overset{CH_3}{\underset{C_2H_5}{>}}C{-}$	NC_5H_{10}	116 (3.2)	1.4944	—	81	Hydrochloride 195–196° (acetone–alcohol)	7.11, 7.20	$C_{12}H_{21}ON$	7.23
(XXVII)	(cyclohexylidene)	NC_5H_{10}	145–146 (2)*	—	—	88	Hydrochloride 226–227° (alcohol) Methiodide 141–143° (acetone–ether)	6.29, 6.33	$C_{14}H_{23}ON$	6.35
(XXVIII)	(cyclopentylidene)	NC_5H_{10}	138–140 (2)	1.5161	1.0110	88.5	Hydrochloride 222.5–223° (acetone–alcohol) Methiodide 143–144° (acetone–alcohol) Picrate 123.5–124° (acetone)	6.62, 6.82	$C_{13}H_{21}ON$	6.75
(XXIX)	(cyclopentylidene)	$N(C_2H_5)_2$	153–154 (12)	1.4943	0.972	78	—	7.03, 6.78	$C_{13}H_{23}ON$	6.70

* M.p. 58–60°.

with 150 ml of water, carefully neutralized with solid sodium carbonate (53 g), and extracted with ether (200 ml). The ether extracts were washed with sodium carbonate solution, and with water, and dried with calcium chloride. After the ether was distilled off, the residue was distilled in vacuo. 118 g (90%) of the acetate was obtained. There was 4 g of tarry residue in the flask. In a similar manner, the acetates of dimethylethynylcarbinol (I) [9], methyl-ethylethynylcarbinol (IV) [9], and ethynylcyclopentanol (IX) [10] were prepared. The constants and yields for these compounds are given in Table 1.

1-Ethynylcyclopentanol-1 Benzoate (X)

To a solution of 50 g (0.45 mole) of 1-ethynylcyclopentanol-1 and 65 g (0.46 mole) of benzoyl chloride in 100 ml of dry benzene, we slowly added, with cooling and stirring, 39.5 g (0.50 mole) of pyridine. Toward the end of the addition, crystals of pyridine hydrochloride began to precipitate. The mixture stood for two days at room temperature, then was washed with 10% sulfuric acid until the pyridine was completely neutralized. The benzene layer was separated and the aqueous layer was extracted with ether (100 ml). The benzene—ether extract was washed with saturated sodium carbonate solution, with water, and dried with potassium carbonate. After the ether and benzene were distilled off, the product, which had partially crystallized, was distilled in vacuo. 78 g (83%) of the benzoate was obtained. The benzoates of (II), (V), and (VIII), and the phenoxyacetates of (III), (VI), dimethylethynylcarbinol, methylethylethynylcarbinol, and 1-ethynylcyclohexanol-1 were prepared in a similar manner. Their constants and yields are given in Table 1.

1-γ-Piperidinopropynylcyclohexanol-1 Acetate (XIX)

A solution of 61.2 g (0.72 mole) of piperidine, 21.6 g of paraform (0.72 mole, calculated as formaldehyde), and 119 g (0.72 mole) of the acetate of 1-ethynylcyclohexanol-1 in 240 ml of dry dioxane was refluxed at weak boiling for 34 hours. On cooling, 100 ml of water was added, the organic layer was separated, and the aqueous layer was extracted with ether. To the organic layer combined with the ether extracts was added carefully, with cooling, 166 ml of 5 N hydrochloric acid. The ether layer was separated (1) and the acid aqueous solution was neutralized, while cooling, with 56 ml of a concentrated ammonia solution and extracted twice with ether (150 ml) (2). The ether extracts (2) were dried with sodium sulfate and, after the ether was distilled off, the product was distilled in vacuo. 105.3 g of the acetate was obtained. There was 9 g of tarry residue.

Found %: N 5.64, 5.58. $C_{16}H_{25}O_2N$.

Calculated %: N 5.32.

The ether extract (1) was dried with calcium chloride; after the ether was distilled off, the product was distilled in vacuo. 19 g of the starting acetate of 1-ethynylcyclohexanol-1 was obtained with b.p. 96-100° at 22 mm; $n^{20}D$ 1.4639. The yield of the acetate (XIX) was 56%, based on the amount of the acetate of 1-ethynyl-cyclohexanol-1 used and 66% based on the amount entering into the reaction. The constants and the yields of the other Mannich bases, which were obtained in a similar manner, are given in Table 2.

1-γ-Piperidinopropynylcyclopentanol-1 (XXVIII)

A solution of 42.1 g (0.17 mole) of the acetate of 1-γ-piperidinopropynylcyclopentanol-1 (XXIII) and 11.2 g (0.2 mole) of potassium hydroxide in 130 ml of 90% alcohol was heated for 2 hours on a water bath. The alcohol was distilled off under a weak vacuum, the residue was treated with 50 ml of water and extracted with ether. To remove traces of alkali, 35 ml of 18% hydrochloric acid was added to the ether solution, and the aqueous layer was separated and neutralized with 20 ml of concentrated ammonia solution. The supernatant oil was extracted with ether and dried with magnesium sulfate. After the ether was distilled off, the product was distilled in vacuo. 31.2 g (88.5%) of (XXVIII) was obtained as a very viscous, light yellow liquid.

Found %: N 6.62, 6.82. $C_{13}H_{21}ON$.

Calculated %: N 6.75.

In a similar manner, other acetylenic aminoalcohols were prepared; their constants and yields are given in Table 3.

SUMMARY

1. A number of acetates, benzoates, and phenoxyacetates of acetylenic aminoalcohols have been prepared by the Mannich reaction with esters of tertiary acetylenic alcohols. The hydrochlorides of the benzoates and phenoxyacetates were prepared for physiological testing of their anesthetic activity.

2. By saponification of the acetates the corresponding acetylenic aminoalcohols were obtained.

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SYNTHESIS OF STEREOISOMERIC 1,2,5-TRIMETHYL-4-ETHYNYL-
-4-PIPERIDOLS. STEREOCHEMISTRY OF THE ACETYLENIC SYNTHESIS

I. N. Nazarov, I. A. Mokhir, B. V. Unkovskii and G. S. Gusakova

M. V. Lomonosov Institute of Fine Chemical Technology, Moscow

In recent years in our laboratory systematic investigations have been carried out on the stereoisomeric 1-
-alkyl-2,5-dimethyl-4-phenyl-4-piperidols and their acyl derivatives for the purpose of exploring new sedative
preparations and explaining the relationship of analgesic activity to spatial configuration [1,2]. As a result of
this work, new domestic preparations have been obtained — promedol, isopromedol, and α-promedol (hydrochlo-
rides of the propionates of the stereoisomeric 1,2,5-trimethyl-4-phenyl-4-piperidols) [1,3], which surpass morph-
ine in analgesic activity 2-10 times, and have found use in clinical practice.

In the development of this research we were interested in the synthesis and investigation of analgesics of
the type of the stereoisomeric 4-aryl-4-piperidylalkyl ketones which, in contrast to promedol, an analog of nizen-
tyl (prodyne) [4], have a ketobemidone (kliradone) structure, first synthesized 10 years ago [5].

Promedone   Nizentyl   Ketobemidone
    (prodyne)   (kliradone)
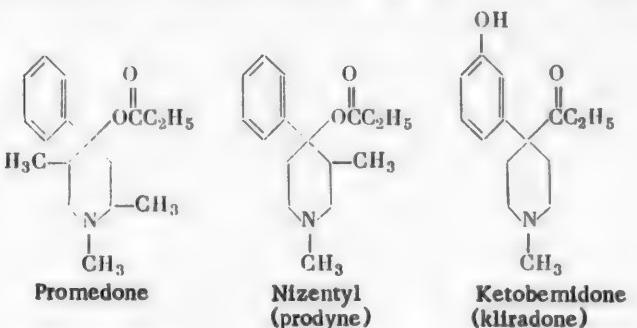
Spatial isomerism is absent in the series of ketobemidone and its known analogs, in connection with which
the synthesis of stereoisomers of 4-aryl-4-piperidylalkyl ketones substituted in the piperidine ring, which were un-
known up to now, opens wide possibilities for the exploration of new sedative agents.

In previous communications from our laboratory [3,6] we have described the synthesis of various 4-ethynyl-
-4-piperidols with different substituents in the piperidine ring, which are produced easily and in good yields from
γ-piperidones and acetylene by the reaction of A. E. Favorskii.
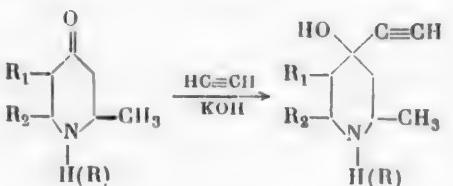
The easy availability of the acetylenic alcohols, and the possibility of preparing from them stereoisomeric analogs of ketobemidone, induced us to investigate in greater detail the spatial isomerism of these compounds.

In the present communication, we describe the synthesis of stereoisomeric 1,2,5-trimethyl-4-ethynyl-4--piperidols (II) under different conditions, and their separation into the individual isomers. The acetylenic alcohols (II) are produced in yields up to 80% by the reaction of 1,2,5-trimethyl-4-piperidone (I) [7] with acetylene, in the presence of powdered potassium hydroxide, in the form of a mixture of the stereoisomers which readily lends itself to separation. Of the four theoretically possible acetylenic alcohols (II) which have a different spatial arrangement of the substituents in the piperidine ring, we have succeeded in isolating only three geometric isomers, which have been designated as the α-, β-, and γ-isomers.
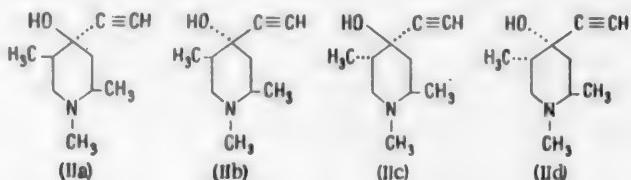
α-Isomer — m.p. 73-74°; hydrochloride — m.p. 200-201°. β-Isomer — m.p. 113-114°; hydrochloride — m.p. 221-222°. γ-Isomer — 177-178°; hydrochloride — m.p. 209-210°.

The fact of the isolation of the three stereoisomeric acetylenic alcohols (II) described above indicates that the piperidone (I) in the presence of powdered potassium hydroxide enters into reaction with acetylene in both of its stereoisomeric forms [cis- (Ia) and trans- (Ib)] which occur in tautomeric equilibrium with the enol form (Ic), and the ratio of the cis- and trans- isomers can vary considerably, depending on the conditions under which the reaction is carried out.
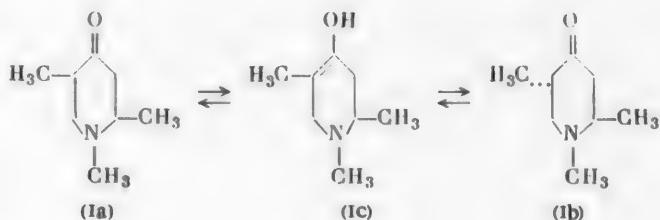
The same sort of stereochemical picture is observed also in the reaction of the piperidone (I) with phenyl lithium [1], in contrast to the reaction with hydrogen cyanide, which proceeds in weakly acid or neutral medium where only one spatial isomer of the cyanohydrin [8] is formed as a result of the absence of the above-mentioned tautomeric equilibrium transitions.

As a result of a series of experiments which were not for the purpose of obtaining strict kinetic data, we succeeded in establishing that the quantitative ratio of the stereoisomeric acetylenic alcohols (II) is not constant, but depends on the reaction conditions, changing under the influence of a number of factors (reaction temperature, duration of the synthesis, pressure).

Under ordinary conditions for the Favorskii reaction (temperature from −8 to −10°, duration 10 hours), the predominant product is the β-isomer of the acetylenic alcohol (II) (64%); the high-melting γ-isomer constitutes 26% of the total mixture of stereoisomeric alcohols (II), while the low-melting α-isomer comprises only 10%. Carrying out the reaction at higher temperatures (0 to +5°) leads to a notable increase in the β-isomer content of the product at the expense of a decrease in the amount of α- and γ-isomers (see table). An increase in the duration of the reaction (longer contact of the reaction product with the potassium hydroxide) also leads to the same results.

Expt. No.	Amt. of piperidone used	Reaction temp.	Excess pressure of acetylene (in atm)	Duration of intro. of ketone (in hrs)	Duration of synthesis (in hrs)	Yield of acetylenic alcohols (in g)	Ratio of isomeric alcohols (in %)		
							α-	β-	γ-
Relationship to pressure									
1	200	−8°	.0	1	9	176.3	10.4	63.2	26.4
2	100	−8	0.5	1	3	89.65	13.7	43.1	43.2
3	200	−8	5	1	3	184.9	18.4	26.4	55.2
4	70.5	−8	15	0.75	3	50.0	23.8	11.85	64.35
Relationship to temperature									
5 *	200	−8	0	1	9	176.3	10.4	63.2	26.4
	100	0	0	1	9	87.2	6.95	71.6	21.35
6 **	200	−8	5	1	3	184.9	18.4	26.4	55.2
	600	0	5	3	3	546.5	8.3	54.7	37.0
	550	+5	5	3	3	474.2	6.45	65.25	28.3

Most interesting and unexpected results were obtained in the synthesis of the acetylenic alcohols (II) under pressure, which was carried out in special reactors [9]. The excess pressure of the acetylene in these experiments varied from 0.5 to 15 atm , while a constant temperature (−8°) and reaction time (4 hours) were maintained in all the syntheses. Separation of the stereoisomeric acetylenic alcohols (II) showed that, under these conditions, the quantitative ratio of the stereoisomers varies distinctly, depending on the magnitude of the excess acetylene pressure (see table).

Analysis of the results obtained indicates that an increase in the excess acetylene pressure leads to a gradual increase in the product of the high-melting γ - and the low-melting α-isomers, which finally become the main products of the reaction. Comparison of the results of experiments carried out at the same excess pressure but at different temperatures show that an increase in the temperature leads to a decrease in the effect of pressure. Under these conditions, as well as at atmospheric pressure, a decrease is observed in the high-melting γ - and the low-melting α-isomer content of the mixture of stereoisomeric acetylenic alcohols (II) and an increase in the amount of β-isomer (see table).

From the data presented, it becomes evident that the quantitative ratio of the isomers (II) can vary and be controlled at the option of the experimenter by changing the reaction conditions. An explanation of such a relationship of spatial isomerism to the conditions of synthesis, which is recorded for the first time, must be sought in the mechanism of formation of the acetylenic alcohols by the Favorskii reaction, which is of a reversible character.

As a result of the high degree of dissociation and lability of some acetylenic alcohols, an exchange reaction (disproportionation) is sometimes observed, with the transfer of the acetylene to a ketone, which forms a more stable acetylenic alcohol. Such a phenomenon often occurs in attempts to synthesize unsymmetrical acetylenic γ -glycols from acetylenic alcohols and ketones, where, along with the expected unsymmetrical acetylenic γ - -glycols, one obtains the more stable acetylenic alcohols or the symmetrical acetylenic γ -glycol that is formed from the latter [10, 11].

A similar dissociation into the starting components under the influence of alkaline agents, which accompanies the exchange reaction with the transfer of hydrogen cyanide, and the formation of a more stable compound, is characteristic also of many cyanohydrins, a fact that is often utilized for preparative purposes [12]. Interesting data were published very recently which indicate that the degree of dissociation, and the stability of cyanohydrins of substituted cyclohexanones depends on their conformation [13].

By analogy with the cyanohydrins, we think that the difference in the conformations of the stereoisomeric acetylenic alcohols (II), which is connected with their spatial configuration, also affects the degree of dissociation and the stability of these alcohols under the conditions of synthesis. The acetylenic alcohols (II) are formed under the influence of steric factors in the synthetic process at a different rate, which results in a predominance of the β - and γ -isomers. On the other hand, since they have a different degree of stability, they also undergo dissociation

to an unequal extent depending on their conformation. Starting with the experimental data obtained, we have come to the conclusion that the β-isomer of the acetylenic alcohol (II) possesses a configuration that provides greater stability, while the configuration of the high-melting γ-isomer promotes its dissociation, as a result of which it decomposes more rapidly under the influence of the potassium hydroxide. The piperidone (I) which is formed as a result of the decomposition of the acetylenic alcohols undergoes isomerization in the alkaline medium, and then again reacts with the excess acetylene in both of its stereoisomeric forms (cis and trans). As a result of this secondary process, a gradual accumulation of the more stable β-isomer takes place in the reaction mass. The rate of introduction of the starting piperidone (I) plays an essential role, since, during this period, isomerization of the piperidone also occurs under the influence of the alkali before it enters into reaction with the acetylene. The parallel course of the transformations mentioned above leads to the establishment of a dynamic equilibrium that depends on the conditions under which the synthesis is carried out, and that determines the final quantitative ratio of the stereoisomeric acetylenic alcohols at the moment that the reaction is completed by hydrolysis.

Raising the temperature of the synthesis leads to a considerable increase in the role of dissociation and a rise in the degree of decomposition of the acetylenic alcohols (II), especially of the high-melting γ- and the low-melting α-isomers, which results in an increase in the amounts of the more stable β-isomer as a consequence of the secondary processes.

In syntheses under pressure, the reaction of the acetylene with the starting piperidone (I) proceeds considerably more rapidly than at atmospheric pressure, and the piperidone does not undergo enolization to the degree that it does in ordinary syntheses. In this connection, the stereoisomers of the acetylenic alcohol (II) that are formed under pressure are predominantly those that correspond to the unenolized trans form of the starting piperidone (Ib). Such isomers are specifically the high-melting γ-isomer, which has the same spatial configuration as the cyanohydrin of the piperidone (I), and the low-melting α-isomer, which, according to all the data, is the epimer of the γ-isomer at the C_4 of the piperidone ring. Furthermore, in syntheses under pressure, the dissociation of the acetylenic alcohols (II) is greatly decreased in connection with a decrease in the time of contact and in increase in the concentration of acetylene, which leads to a shift in the dynamic equilibrium toward the formation of the undissociated compound. For this reason, the decomposition of the high-melting γ- and the low-melting α-isomers is suppressed under pressure. As the pressure rises, the content of these isomers in the mixture of stereoisomeric alcohols sharply increases, and they become the main reaction products.

Elucidation of problems of the stereochemistry of the acetylenic alcohols (II), investigation of their spatial configuration, and conformational analysis will be the subjects of subsequent communications, in connection with which, concrete spatial configurations are not yet ascribed to the acetylenic alcohols (II).

Along with the stereoisomeric acetylenic alcohols (II), the symmetrical acetylenic γ-glycol — di-(1,2,5-trimethyl-4-hydroxy-4-piperidyl)acetylene (III) — also is obtained. This glycol can be formed both by the direct reaction of acetylene with the piperidone (5%) (I) [11], and by the reaction of the latter with the acetylenic alcohols (20%) (II).
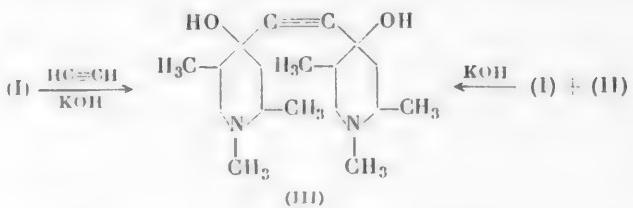
We have shown that the glycol (III) is found to be the main product of the reaction of the piperidone (I) and acetylene in the case of a prolonged synthesis (60 hours) at room temperature, and that it is formed in yields up to 25% along with a trifling amount of the β-isomer of the acetylenic alcohol (II) and the recovery of a considerable part of the unreacted piperidone. It is interesting to note the complete absence in the reaction product of the high-melting γ- and the low-melting α-isomers of the acetylenic alcohol (II), which are totally decomposed as a result of prolonged synthesis at a high temperature.

1,2,5-Trimethyl-4-piperidone (I) was prepared by a previously described method [7], and usually had the following constants: b.p. 68-69° at 4 mm, $n^{20}D$ 1.4580.

1,2,5-Trimethyl-4-ethynyl-4-piperidol (II). 1. Synthesis at atmospheric pressure. In a three-necked flask fitted with a mechanical stirrer, a mercury seal, a tube for the introduction of acetylene, a dropping funnel, and a reflux condenser, were placed 200 g of powdered potassium hydroxide and 2 liters of dry ether. The ether was saturated with acetylene over the course of 4 hours while the mixture was cooled with ice and salt (−8°). Then 200 g of 1,2,5-trimethyl-4-piperidone (I) in 200 ml of ether was added at the same temperature with continuous stirring and simultaneous passing through of acetylene. After addition of the piperidone, stirring was continued at constant temperature for 9 hours, and then the reaction mass was hydrolyzed with 300 ml of water. The white, crystalline precipitate that separated out was filtered off and washed twice with hot water. After recrystallization from alcohol, 46.6 g of the high-melting γ-isomer (II) was obtained with m.p. 177-178°; it gave no depression in melting point when mixed with a previously described sample [3].

Hydrochloride: m.p. 209-210° (from alcohol).

Found %: N 6.98, 7.02. $C_{10}H_{18}ONCl$.

Calculated %: N 6.88.

Methiodide: m.p. 246-247° (from alcohol).

Found %: N 4.32, 4.26. $C_{11}H_{20}ONI$.

Calculated %: N 4.53.

The ether layer was separated, the aqueous layer was saturated with potassium hydroxide and repeatedly extracted with ether. The ether extracts were neutralized with carbon dioxide gas to a slight turbidity and dried with calcined sodium sulfate. After the ether was distilled off, the residue partially crystallized. The crystalline material was carefully pulverized by grinding, and was separated from the oily product by washing three times with dry ether. 87.4 g of the β-isomer of (II) was obtained as a white crystalline material with m.p. 113-114° (after recrystallizing twice from benzine or acetone); it did not give any depression in a mixed melting point test with a previously described sample [3].

Hydrochloride: m.p. 221-222° (from alcohol).

Found %: N 6.89, 6.95. $C_{10}H_{18}ONCl$.

Calculated %: N 6.88.

Methiodide: m.p. 225-226.5° (from alcohol).

Found %: N 4.40, 4.28. $C_{11}H_{20}ONI$.

Calculated %: N 4.53.

The oily residue that did not crystallize was distilled in vacuo; the following fractions were obtained: 1st, b.p. 60-70° at 3 mm, 16.45 g; 2nd, b.p. 84-88° at 3 mm, 42.2 g; 3rd, b.p. 95-120° at 3 mm, 4.6 g; 4th, b.p. 180-191° at 3 mm, 7.9 g.

The 1st fraction was the starting piperidone (I). The 2nd fraction crystallized partially upon standing for 4 days. The crystalline product after careful grinding was separated from the oily material by washing with dry ether. An additional 20.0 g of the β-isomer of (II) was obtained, which melted at 111-113°, and was the practically pure isomer. The 3rd fraction quickly crystallized. After recrystallization from water, an additional 4 g of the β-isomer of (II) was obtained, with m.p. 113-114°. The 4th fraction was a viscous orange oil, which quickly solidified to a solid ice-like mass and proved to be the acetylenic γ-glycol — di-(1,2,5-trimethyl-4-hydroxy-4--piperidyl)acetylene (III).

Dihydrochloride: m.p. 290-291° (from alcohol).

Found %: N 7.21, 7.31. $C_{18}H_{34}O_2N_2Cl_2$.

Calculated %: N 7.36.

Dimethiodide: m.p. 285-286° (from 80% alcohol).

Found %: N 4.59, 4.64. $C_{20}H_{38}O_2N_2I_2$.

Calculated %: N 4.73.

In all, 111.4 g of the β-isomer of (II) was isolated in this experiment.

The oily residue (20.3 g) obtained after distilling off the ether from the filtrate was distilled in vacuo and had the appearance of a viscous, clear material (b.p. 84-85° at 3 mm); on prolonged standing it did not crystallize, but gradually took on an orange color.

Hydrochloride: m.p. 200-201° (after 3 recrystallizations from alcohol); big, hard, shining rosettes.

Found %: N 7.10, 7.08. $C_{10}H_{18}ONCl$.

Calculated %: N 6.88.

When the alcoholic mother liquors were concentrated, a slight amount of a difficultly separable mixture of the hydrochlorides of the α- and β-isomers was isolated, which melted at 214-219°.

The hydrochloride with m.p. 200-201° was converted in the usual way to the oily base, which, after distillation in vacuo (b.p. 83-85° at 3 mm) quickly crystallized completely. After 2 recrystallizations from benzine, 18.3 g of the low-melting α-isomer of (II) was obtained with m.p. 73-74°.

Found %: N 8.32, 8.60. $C_{10}H_{17}ON$.

Calculated %: N 8.32.

Methiodide of α-isomer: m.p. 256-257° (from alcohol).

Found %: N 4.37, 4.30. $C_{11}H_{20}ONI$.

Calculated %: N 4.53.

In all, 176.3 g of the stereoisomeric acetylenic alcohols (II) was obtained in the present experiment. Yield 74.5%.

2. Syntheses at elevated pressure. The preparation of the acetylenic alcohols (II) under pressure was carried out in special steel reactors, whose construction and the method of carrying out the syntheses have been described in a previous communication [9].

The results of the separation of the stereoisomers and the relationship of their quantitative ratio to pressure and temperature are given in the table.

Di-(1,2,5-trimethyl-4-hydroxy-4-piperidyl)acetylene (III). In a round-bottomed, three-necked flask fitted with a mechanical stirrer, mercury seal, dropping funnel, reflux condenser with a calcium chloride tube, and a tube for the introduction of acetylene were placed 60 g of powdered potassium hydroxide and 200 ml of dry ether. While the mixture was stirred and cooled with ice water, 56.4 g of 1,2,5-trimethyl-4-piperidone (I) was added, and 4.5 liter of acetylene was run into the mixture over the course of 3 hours in a slow stream, and then another 4.5 g was added rapidly. The mixture was further stirred at room temperature (+20°) for 60 hours without adding acetylene, after which the reaction mass was hydrolyzed with 160 ml of water. The ether layer was separated, the water layer was saturated with solid alkali, and repeatedly extracted with ether. The combined ether extracts were neutralized with carbon dioxide until the solution became turbid and were dried with calcined sodium sulfate. After the ether was distilled off, the oily residue was distilled in vacuo. The following fractions were obtained: 1st, b.p. 65-80° at 3 mm, 31 g; 2nd, b.p. 94-105° at 3 mm, 2.7 g; 3rd, b.p. 180-190° at 3 mm, 14 g. Residue from distillation, 2 g.

The 1st fraction was starting piperidone (I). The 2nd fraction was a colorless, viscous liquid that slowly started to crystallize in the receiver. After recrystallization from water, it melted at 113-114° and proved to be the β-isomer of the acetylenic alcohol (II). The 3rd fraction was a very viscous, orange liquid that solidified to a solid, ice-like mass, the acetylenic γ-glycol (III). The yield was 23%.

The dihydrochloride of the glycol after recrystallization three times from anhydrous alcohol melted at 290-291° and gave no depression in melting point when mixed with a sample obtained in previous experiments.

The dimethiodide after recrystallization from anhydrous alcohol melted at 285-286° and also gave no depression in melting point when mixed with a sample obtained in the previous experiment.

SUMMARY

1. By the reaction of 1,2,5-trimethyl-4-piperidone with acetylene in the presence of powdered potassium hydroxide, a mixture of three of the four theoretically possible stereoisomeric 1,2,5-trimethyl-4-ethynyl-4-piperidols was obtained in 80% yield; this indicates that the piperidone enters into reaction with acetylene in alkaline medium, in contrast to the reaction with hydrogen cyanide, in both of its stereoisomeric forms (cis and trans) which occur in tautomeric equilibrium.

2. The quantitative ratio of the stereoisomeric acetylenic alcohols depends upon the reaction conditions (pressure, temperature, duration of synthesis), and can be changed at the option of the experimenter. The ratio of the stereoisomers is changed most sharply by increasing the excess pressure of the acetylene.

In syntheses under pressure, the predominant stereoisomeric acetylenic alcohols in the mixture are the low-melting α- and the high-melting γ-isomers, which correspond to the unenolized trans form of 1,2,5-trimethyl--4-piperidone and have the same spatial configuration as the cyanohydrin of 1,2,5-trimethyl-4-piperidone.

3. An explanation has been given of the relationship of spatial isomerism of the acetylenic alcohols to the reaction conditions from the point of view of the reversible nature of the synthesis and the different degree of dissociation of the isomers under the influence of potassium hydroxide.

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N-ALLYLPYRIDONE-2 AND 2-ALLOXYPYRIDINE AND
THEIR HYDROGENATION PRODUCTS

B. I. Mikhant'ev, E. I. Fedorov, A. I. Kucherova
and V. P. Potapova

Voronezhskii State University

Original article submitted May 15, 1958

A. E. Chichibabin [1] prepared N-allylquinolone-2 by the reaction of the potassium salt of quinolone-2 with allyl bromide, and attempted to synthesize 2-alloxyquinoline from 2-chloroquinoline and sodium allylate. However, on distillation under normal pressure, the 2-alloxyquinoline was converted to N-allylquinolone-2.

Taking into consideration the similarity in the chemical properties of quinolone-2 and pyridone-2, we decided to carry out an analogous synthesis, starting with the sodium salt of pyridone-2, and we obtained N-allyl-pyridone-2 (I).

By the reaction of 2-chloropyridine with sodium allylate, 2-alloxypyridine (II) was obtained, and to prevent the isomerization of the latter to N-allylpyridone-2, the product was distilled off from the reaction mixture in vacuo at a residual pressure of 1.5 mm.

By hydrogenation of the N-allylpyridone-2 and 2-alloxypyridine over Raney nickel, we obtained the corresponding N-n-propylpyridone-2 (III) and 2-propoxypyridine (IV).
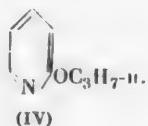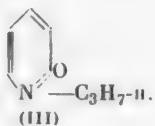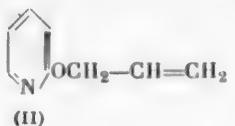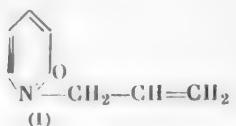
EXPERIMENTAL

N-Allylpyridone-2 (I)

To 10 g of the sodium salt of pyridone-2 dissolved in 20 ml of anhydrous alcohol was added 35 g of allyl chloride. The mixture was refluxed for 2.5 hours. The precipitate of sodium chloride that separated out was filtered off, washed with alcohol, and the filtrate was distilled. 7.4 g (64%) of colorless oil was distilled off.

B.p. 88.5-91.5° (1.5 mm), n^{20}D 1.5608, d^{20}_4 1.0814, MR_D 40.47; calculated 39.49.

Picrate m.p. 104.5-105.5°.

Found %: N 10.32, 9.93; C 70.93, 70.64; H 6.6, 6.59. M 135.5, 135.8. C_8H_9ON.

Calculated %: N 10.37; C 71.08; H 6.71. M 135.168.

2-Alloxypyridine (II)

2 g of metallic sodium was dissolved in 19.5 g of allyl alcohol and 5.1 g of 2-chloropyridine was added. The mixture was refluxed on a water bath for 2 hours. The precipitate of sodium chloride that separated out was

filtered off. The allyl alcohol was distilled off from the filtrate, and the residue was treated with water; the oil was separated off. The water layer was extracted with ether. The product with the ether extract was dried with calcined potassium carbonate, and the ether was distilled off. The residue was distilled in vacuo. The yield was 3.5 g (57.7%). Colorless oil with the odor of allyl alcohol; a sample gave a negative Beilstein test for halogen.

B.p. 30-35° (1.5 mm), $n^{20}D$ 1.5085, d^{20}_4 1.0234, MR_D 39.4; calculated 40.66.

Picrate m.p. 105.5-106.5°. A mixed sample of the picrates of N-allylpyridone-2 and 2-alloxypyridine melted with a depression of 20° (85-90°).

Found %: N 10.17, 10.09. M 130.2, 132.1. C_8H_9ON.

Calculated %: N 10.36. M 135.168.

N-n-Propylpyridone-2 (III)

1.5 g of Raney nickel was added to 13.3 g of N-allylpyridone-2 in 25 ml of alcohol. At a pressure of 200 mm of water, 20°, and with continuous shaking of the mixture, 2.215 ml of hydrogen was absorbed in 3 hours (calculated amount of hydrogen at 755 mm was 2383 ml). The catalyst was filtered off, the alcohol was distilled off on a water bath, and the residue was distilled. 11.95 g (88.6%) of a colorless oil was distilled off.

B. P. 123-124° (13 mm), 263.5-264°, $n^{20}D$ 1.5385, d^{20}_4 1.0711, MR_D 40.09; calculated 39.96.

According to the data of [2], b.p. 263-264°$_{corr.}$ (730 mm).

Picrate m.p. 95.5-96.5°.

Found %: N 10.00, 10.17. M 137.8, 138.0. $C_8H_{11}ON$.

Calculated %: N 10.22. M 137.176.

2-n-Propoxypyridine (IV)

1 g of Raney nickel was added to 5.593 g of 2-alloxypyridine in 15 ml of alcohol. With continuous shaking at a pressure of 200 mm of water and 22°, 1060 ml of hydrogen was absorbed (calculated amount of hydrogen at 754 mm was 1010 ml). The catalyst was filtered off, the alcohol was distilled off on a water bath, and the residue was distilled. 2.5 g of colorless oil (44.7%) was distilled off. The product partially distilled with the alcohol, as was established by the formation of a picrate in the alcoholic fraction. The constants of the substance obtained agree with the literature data [3].

B.p. 43° (7 mm); $n^{20}D$ 1.4900.

Picrate m.p. 116.5-118°.

Found %: N 10.0, 9.96. $C_8H_{11}ON$.

Calculated %: N 10.21.

SUMMARY

1. N-allylpyridone-2 was obtained by the action of allyl chloride on the sodium salt of pyridone-2.

2. 2-Alloxypyridine was synthesized by the reaction of 2-chloropyridine with sodium allylate.

3. By the hydrogenation of N-allylpyridone-2 and 2-alloxypyridine, the corresponding N-n-propylpyridone-2 and 2-n-propoxypyridine were obtained.

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INVESTIGATIONS IN THE FIELD OF CONJUGATED SYSTEMS.

XCIX. THE SYNTHESIS OF GERANYL CHLORIDE BY THE TELOMERIZATION OF ISOPRENE WITH ITS 1,4-HYDROCHLORIDE*

A. A. Petrov, Kh. V. Bal'yan, Yu. I. Kheruze, E. Yu. Shvarts
and L. L. Cherenkova

Lensovet Technological Institute, Leningrad

Original article submitted May 31, 1958

In a recently published article, a detailed description was given for the synthesis of geranyl chloride by the telomerization of isoprene with its hydrochloride in the presence of catalysts — stannic chloride or zinc chloride [1]. In this article, the results of our further investigations in search of other catalysts for this reaction are presented.

We have studied the action on a mixture of isoprene with its 1,4-hydrochloride (1-chloro-3-methylbutene- -2) of titanium tetrachloride, a mixture of titanium tetrachloride with stannic chloride, stannic chloride in the presence of an excess of hydrogen chloride, stannic chloride and cupric chloride, ferric chloride, potassium bifluoride, zinc borofluoride, and bismuth bromide.

Titanium tetrachloride appears to have a similar catalytic effect to that of stannic chloride on the yield of telomer, of terpene chlorides, and of geranyl chloride. However, titanium tetrachloride is less convenient to use because of its great hydroscopicity. A mixture of stannic chloride and titanium tetrachloride acts the same as pure stannic chloride. In the presence of an excess of hydrogen chloride, the catalytic properties of stannic chloride also are not improved. The rate of reaction under these conditions decreases greatly and it is necessary to resort to heating.

Cupric chloride does not have a noticeable catalytic action. Addition of it to stannic chloride does not improve the yield of geranyl chloride.

In the presence of ferric chloride the reaction starts only upon heating to 35-37°. While there is small difference in the amount of telomer, the terpene content of the telomer is one-half and the yield of geranyl chloride is one-third, or less, of that in the presence of stannic chloride. In comparison with zinc chloride, zinc borofluoride has the advantage that it can be used in the dry form, and it is not necessary to heat the reaction mixture.

The catalytic action of bismuth bromide approaches that of the zinc compounds.

Thus, as a result of this investigation, it has been established that two groups of catalysts exist for the telomerization of isoprene with its hydrochlorides. The catalysts of the first group ($SnCl_4$, $TiCl_4$, $FeCl_3$) promote the formation of higher telomers. The catalysts of the second group [$ZnCl_2$, $Zn(BF_4)_2$, $BiBr_3$] promote breaking off of the reaction at the stage of the formation of the terpene chlorides. However, the cause of this breaking off, as has been established previously, is the partial cyclization of geranyl chloride to terpenyl chloride. Therefore, the geranyl chloride content of the terpene fraction of the telomer turns out to be considerably less than in the case where catalysts of the first group are used.

Hydrogen chloride inhibits the beginning of the telomerization; however, it does not affect its nature.

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*Diene compounds. LXXIV. Reaction of dienes with halogen derivatives. X.

Results of Experiments on Telomerization

Expt. No.	Catalyst	Increase in sp. gr. of mix.	Isoprene reacted (in %)	Amt. of telomer (in g)	Terpene chlorides (in % by wt. of telomer)	Yield of geranyl chloride	
						in % of terpene fraction	in % of theor.
1	$SnCl_4$	0.066	44.3	44.0	33.7	39.3	13.3
2	$SnCl_4$	0.061	38.9	38.9	34.7	46.5	16.0
3	$SnCl_4$	0.057	37.5	38.4	37.4	49.5	16.9
4	$SnCl_4$	0.050	33.2	32.5	42.4	48.6	20.6
5	$TiCl_4$	0.078	43.0	42.0	30.2	45.7	13.7
6	$SnCl_4 + TiCl_4$	0.050	36.9	36.9	36.2	50.3	17.6
7	$SnCl_4 + HCl$ (gaseous)	0.062	32.5	38.4	44.3	48.0	21.2
8	$SnCl_4 + HCl$ (in ether)	0.034	30.0	35.5	36.0	44.5	16.2
9	$SnCl_4 + CuCl_2$	0.050	35.6	35.2	40.0	41.0	16.4
10	$FeCl_3$ (in alcohol)	0.061	35.7	34.8	18.5	28.1	5.2
11	$Zn(BF_4)_2$	0.055	35.3	34.6	46.3	34.8	16.3
12	$BiBr_3$	0.053	39.1	38.3	45.5	36.9	16.7

EXPERIMENTAL

All the experiments were carried out with identical amounts of isoprene (39 g) and its primary hydrochloride (60 g) in methylene chloride (30 g). The form of the apparatus, the telomerization conditions, the isolation and investigation of the reaction products did not differ from those previously described in detail [1]. The results of the investigations are given in the table, where for comparison we have also presented experiments on the use of $SnCl_4$ as catalyst with a different extent of conversion.

Remarks on Experiments 1-12

Experiments 1-4 have been described in detail in the previous communication.

Experiment 5. A 17% solution of $TiCl_4$ in CH_2Cl_2 (4 ml) was used. When the catalyst was added, strong evolution of heat and formation of smoke (TiO_2) were observed. The temperature was kept not higher than 35°. The reaction was over in 5 min.

Experiment 6. A mixture of 5% solutions of $SnCl_4$ and $TiCl_4$ in CH_2Cl_2 was used.

Experiment 7. 1.5 ml of 5% solution of $SnCl_4$ in CH_2Cl_2 was added to the reaction mixture, and a current of dry HCl was passed through. The reaction was carried out at 12° for 1 hour and 45 min.

Experiment 8. Ether (10 ml) saturated with HCl was added to the reaction mixture. Then 2 ml of 5% solution of $SnCl_4$ in CH_2Cl_2 was added. The reaction did not start. After addition of another 3.5 ml of the same solution of the catalyst and heating to 27°, the reaction started and was ended in 2 hours 35 min.

Experiment 9. 0.5 g of cupric chloride ($CuCl_2 \cdot 2H_2O$) in 1 ml of alcohol was added. Reaction did not go. We succeeded in starting the telomerization by the addition of 1.5 ml of $SnCl_4$ in CH_2Cl_2, and heating to 27°. At this temperature, the reaction was concluded in 3 hours 10 min.

Experiment 10. Ferric chloride (anhydrous) was added in 25% methanol solution (3.7 ml). The reaction started only upon heating to 35-37°. At this temperature, it was concluded at the end of 15 min.

Experiment 11. 0.7 g of zinc bifluoride was added in the dry form. A rise in temperature was observed. The reaction was carried out at 20° with external cooling in 1 hour 5 min.

Experiment 12. 0.2 g of bismuth bromide was added. The reaction was accompanied by the evolution of heat. It was carried out at 30° in 2 hours.

SUMMARY

1. The telomerization of isoprene with its 1,4-hydrochloride in the presence of different catalysts has been investigated.

2. It has been established that all the catalysts investigated can be divided into two groups on the basis of the nature of their action. Catalysts of the first group promote the formation of higher telomers. Catalysts of the second group with the same extent of conversion give a larger yield of terpene chlorides, but their geranyl chloride content is lowered.

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* Original Russian pagination. See C.B. translation.

INVESTIGATIONS IN THE FIELD OF CONJUGATED SYSTEMS

C. THE ORDER OF ADDITION OF BROMINE TO PHENYLBUTENYNES*

A. A. Petrov and T. V. Yakovleva

Lensovet Technological Institute, Leningrad

Original article submitted May 31, 1958

It has been shown previously that the closest homologs of vinylacetylene, which differ in the position of the methyl group, add bromine differently. Penten-1-yne-3 and 2-methylbuten-1-yne-3 add bromine at the double bond, penten-3-yne-1, like unsubstituted vinylacetylene, at the triple bond, and in the 1,4-position [1]. These peculiarities in the order of addition of bromine were explained on the basis of an assumed shift of the electron cloud of the conjugated system under the influence of the methyl group, as a result of which the double bond is activated in the first two instances, and the triple bond in the last ones.
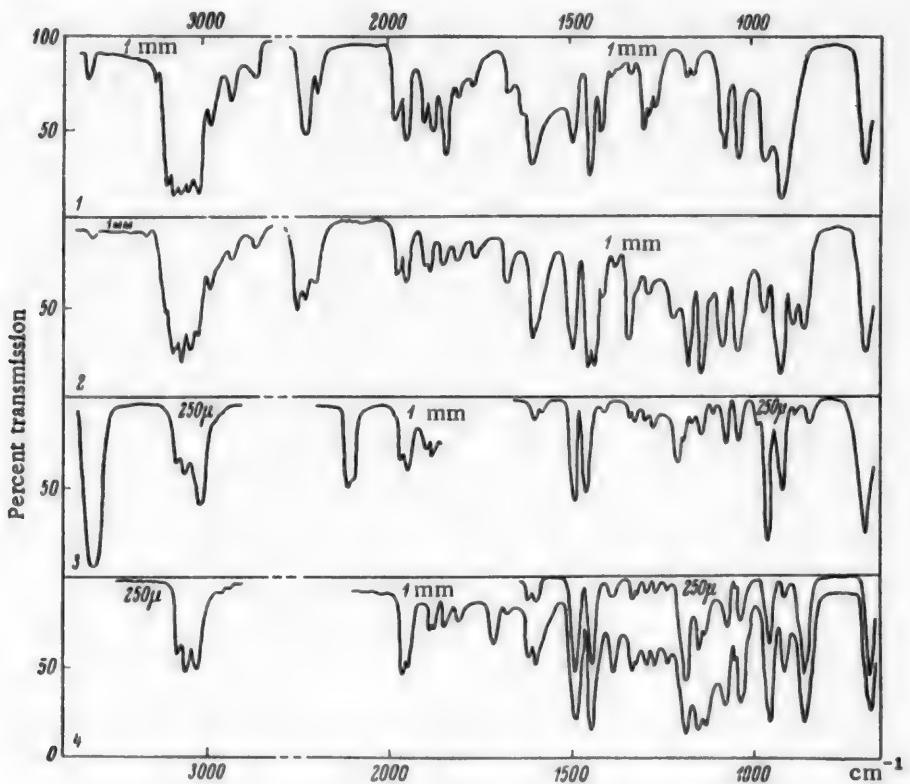
Infrared absorption spectra: 1) solution of 1-phenylbuten-3-yne-1 in CCl_4; 2) solution of its bromination products; 3) solution of 1-phenylbuten-1-yne-3 in CCl_4; 4) solution of its bromination products.

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*Enyne compounds XXVI.

Most Important Frequencies of the Infrared Spectra of the Hydrocarbons and Their Bromides (solutions in CCl_4)*

C_6H_5—C≡C—CH=CH$_2$	Bromides	C_6H_5—CH=CH—C≡CH	Bromides
680 s	680 s	685 vs	687 s
—	849 m	835 m	860 vs
—	878 m	875 w	—
915 vs	915 s	915 s	915 w
957 s	957 s	954 vs	954 s
1028 s	1028 s	1032 m	1032 m
1069 s	1070 s	1070 m	1070 m
1081 m	—	—	—
—	1130 vs	1134 m	1134 m
1156 w	—	1152 w	1149 s
1175 w	1170 s	1180 m	1185 vs
—	1208 m	1205 m	—
1260 m	—	1268 w	1268 w
1277 m	1277 m	—	—
1289 m	—	1291 w	1291 w
1326 w	1333 s	1333 w	1333 w
1410 m	1408 w	1404 w	—
—	1428 s	—	—
1442 s	1442 s	1454 s	1454 vs
1490 s	1486 s	1492 s	1492 vs
1600 s	1603 s	1600 m	1600 m
1631 m	—	—	1623 m
1668 w	1670 s	—	—
1845 s	1845 m	—	—
1874 s	1879 m	1876 vw	1874 ovw
1891 m	1891 m	1891 vw	1892 ovw
1946 s	1948 m	1945 w	1947 w
1963 m	1965 m	1962 w	1958 w
—	—	2094 w	—
—	—	2103 w	—
2184 m	2193 m	—	—
2220 s	2220 m	—	—
2245 o.vw	2242 s	—	—
2918 m	2923 w	—	—
2974 m	2979 m	—	—
3011 o. vs	3020 s	3023 s	3027 m
3037 o. vs	3035 s	—	—
3054 o. vs	3060 vs	3060 m	3060 m
3080 o. vs	3084 vs	3082 m	3080 m
3099 o. vs	3100 m	—	—
—	—	3300 vw ·	—

*Designations of intensities (v.s. — very strong, s — strong, m — medium, w — weak, v.w. — very weak) relate to a 0.25-mm layer of hydrocarbon (II) and a 1-mm layer of (I).

It was of interest to compare these data with data on the order of addition of bromine to phenyl derivatives of vinylacetylene of various structures. For this purpose, we determined the order of addition of the first molecule of bromine to two isomeric phenyl-substituted vinylacetylenes: 1-phenylbuten-3-yne-1 (I) and 1-phenylbuten-1--yne-3 (II). In the literature, corresponding data are absent; only the addition to the two hydrocarbons of two molecules of bromine with the formation of crystalline tetrabromides is described [2].

To avoid isomerization and polymerization of the dibromides upon heating, they were not isolated from the solutions in pure form. The structures of the dibromides were judged on the basis of a comparison of the infrared spectra of solutions of the hydrocarbons (I) and (II) in CCl_4 with solutions of the products of their bromination with one molecule of bromine in the same solvent. It had been shown previously that study of the infrared spectra permits reliable establishment of the structure of the products of addition of halogens to vinylacetylenic hydrocarbons [1,3].

In the infrared spectrum of hydrocarbon (I) the frequencies 3099, 1631, 957, and 915 cm^{-1} correspond to the vinyl group, and the frequencies 2184, 2220, and 2245 cm^{-1} to the acetylenic bond. In the Raman spectrum of

this hydrocarbon, the multiple bonds are characterized by the frequencies 1631, 2186, and 2223 cm^{-1} [4]. In the infrared spectrum of hydrocarbon (II) the frequencies 1600 and 954 cm^{-1} correspond to the ethylene grouping, and 3300, 2094, and 2103 cm^{-1} to the acetylenic group. In the Raman spectrum, similar frequencies are present for the multiple bonds — 1611 and 2104 cm^{-1} [4].

In the figure, transmission curves are given for solutions in CCl_4 of hydrocarbons (I) and (II) and their bromination products. The corresponding frequencies are compared in the table. From these data, it can be seen that in the bromination of hydrocarbon (I) the triple bond is practically not involved, additional absorption in the region 1950 cm^{-1} (the region of absorption of the allene group) does not arise, and absorption in the region 1600 to 1650 cm^{-1} diminishes (the frequency 1631 cm^{-1} disappears).

Thus, bromination of hydrocarbon (I) goes predominantly at the double bond with the formation of the acetylenic dibromide:

$$C_6H_5-C{\equiv}C-CHBr-CH_2Br$$
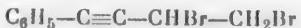
It is possible that the vinyl group is not completely consumed, and the bromine is partially expended in the formation of the tetrabromide, since, in the bromide spectrum, the frequencies of the acetylenic group of the hydrocarbon (2193 and 2220 cm^{-1}) are preserved along with a reinforcement of the frequency of the unconjugated acetylenic bond 2242 cm^{-1}. Also, the deformation frequencies of the vinyl group (915 and 957 cm^{-1}) are preserved. Similar phenomena have been observed on hydrogenation and bromination of vinylalkylacetylenes [1,5].

As a result of the bromination of hydrocarbon (II), the frequencies connected with the presence of the triple bond (3300, 2094, and 2103 cm^{-1}) disappear completely, and the absorption in the region 1950 and 1620 cm^{-1} is strengthened. These data indicate the addition of bromine in the 1,4-position and at the acetylenic bond with the formation of the dibromides:

$$C_6H_5-CHBr-CH{=}C{=}CHBr \ \& \ C_6H_5-CH{=}CH-CBr{=}CHBr$$

Thus, as a result of this investigation, it has been established that when the position of the phenyl group is changed in the vinylacetylenic system, the order of addition of bromine changes in the same way as in the case of a shift of a methyl group. Apparently, the site of the initial attack and of the addition of the whole molecule of bromine depends on the distribution of the electron density in the conjugated system.

$$C_6H_5-C{\equiv}C-CH{=}CH_2 \qquad C_6H_5-CH{=}CH-C{\equiv}CH$$
$$(I) \qquad\qquad\qquad (II)$$

The dipole moments of the phenylvinylacetylenes favor some shift of the electron cloud toward the end carbon atom under the influence of the phenyl group. The dipole moment of the hydrocarbon (I) is much decreased (0.27D), and on the other hand, the dipole moment of hydrocarbon (II) is increased (0.97D) in comparison with the moment of vinylacetylene (0.77D) [6]. Consequently, the phenyl radical in the first instance opposes the usual shift of the electrons in the vinylacetylene system in the direction of the acetylenic bond, and in the second instance it reinforces this shift. The infrared spectrum of hydrocarbon (I) is distinguished by a more intense absorption in the region 1600-1650 cm^{-1} in comparison with the spectrum of hydrocarbon (II), which also indicates a shift of the electron cloud in the first compound toward the ethylenic bond [7]. Probably at the moment of the electrophilic attack of the bromine molecule this static effect reinforces the dynamic effect that acts in the same direction. It also should be taken into account that, in both instances, the end carbon atoms appear to be the most sterically available.

EXPERIMENTAL

The starting hydrocarbons were prepared in our laboratory by N. A. Borovikova and Yu. I. Kheruze; 1-phenyl-buten-3-yne-1 by the dehydration over potassium hydroxide of 1-phenylbutyne-1-ol-4, and 1-phenylbuten-1-yne-3 by the dehalogenation of the reaction product of vinylacetylene with phenyldiazonium chloride [8]. Both hydrocarbons had constants close to those given in the literature.

Bromination was carried out in 10% solution of the hydrocarbon in CCl_4 with a 15% bromine solution (with

10% excess) in the same solvent. The solutions after bromination were brought to a given volume (10 ml). Solutions of the hydrocarbons of the same molar concentration were prepared simultaneously.

The infrared spectra were determined in an IKS-14 spectrophotometer up to 5μ with a LiF prism, and from there on with a NaCl prism. The experimental data are given in the table and the figure.

SUMMARY

1. The order of addition of bromine to the isomeric phenylvinylacetylenes 1-phenylbuten-3-yne-1 and 1-phenylbuten-1-yne-3 has been determined by the method of infrared spectroscopy.

2. It has been shown that 1-phenylbuten-3-yne-1 adds bromine at the double bond, but its isomer adds at the triple bond and in the 1,4-position.

3. An explanation has been given for this mechanism on the basis of the theory of electron shifts.

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* Original Russian pagination. See C.B. translation.

THE INTERACTION OF TETRAHYDROFURAN WITH HALOSILANES

N. I. Shuikin, I. F. Bel'skii and I. E. Grushko

Institute of Organic Chemistry, Academy of Sciences, USSR

Original article submitted April 18, 1958

The organic oxides whose chemical properties have been studied most thoroughly are the olefinic oxides. The diversity of their reactions is associated with the facility of cleavage of the α-oxide ring under the action of various chemical agents to give aliphatic compounds containing various functional groups.

Much less attention has been paid to the chemical transformations of γ-oxides — tetrahydrofuran and its homologs. These are characterized by a considerably poorer reactivity. Their utilization in organic syntheses is extremely important due to the possibility of converting them into 1,4-bifunctional derivatives of the aliphatic series, and to the fact that tetrahydrofuran derivatives are fairly easily accessible and cheap starting substances.

Papers have been published on the susceptibility of the tetrahydrofuran ring to cleavage under the action of hydrogen halides [1-5], metal halides [6], and chlorides of organic and inorganic acids [7,8]. Alexander and Schniepp [8] studied the reaction of tetrahydrofuran with $POCl_3$, $SiCl_4$, and $SOCl_2$ in presence of H_2SO_4 or $ZnCl_2$, and obtained only 4,4-dichlorobutyl ether. Sauer [9] heated tetrahydrofuran with dimethyldichlorosilane in presence of $AlCl_3$ at 125-130° and obtained 1,4-dichlorobutane together with polysiloxanes. Cumada and Hattori established [10] that treatment of some ethers with halosilanes in a closed vessel at 180-190° leads to good yields of organic mono- and dihalides. For example, the reaction of tetrahydrofuran with $SiCl_4$, $C_2H_5SiCl_3$ and $(CH_3)_2SiBr_2$ gave 1,4-dihalobutanes, while tetrahydropyran and $(CH_3)_2SiBr_2$ gave 1,4-dibromopentane. It should be noted that in all of the above investigations the tetrahydrofuran ring was cleaved at both of the C—O bonds with elimination of the oxygen atom, with the result that 1,4-dihaloalkanes were obtained from tetrahydrofuran and its homologs.

We recently established [11] that tetrahydrofuran enters into reaction with silicon tetrachloride under the catalytic influence of anhydrous zinc chloride and gives 1,4-dichlorobutane and di(δ-chlorobutoxy)-dichlorosilane. The second compound predominates.

In the present work, we studied the reaction of tetrahydrofuran with alkyl- and arylchlorosilanes containing two or three atoms of chlorine. It was found that the reaction only goes in presence of anhydrous zinc chloride. It also goes in different directions, depending on the number of chlorine atoms in the chlorosilane molecule.

Methyldichlorosilane and dimethyldichlorosilane cleave the tetrahydrofuran ring at both of the C—O bonds with formation of 1,4-dichlorobutane as the main product:

$$\square_O + (CH_3)_2SiCl_2 \xrightarrow{(ZnCl_2)} \underset{\underset{Cl}{|}}{CH_2}-CH_2-CH_2-\underset{\underset{Cl}{|}}{CH_2} \qquad (I)$$
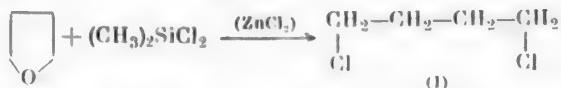
The reaction of tetrahydrofuran with alkyl- and aryltrichlorosilanes differs from that with dichlorosilanes in that the ring is opened at one C—O bond and chloro-substituted esters of orthosilicic acid are formed:

$$\square_O + RSiCl_3 \xrightarrow{(ZnCl_2)} \overset{\overset{R}{|}}{Cl_2Si}-OCH_2CH_2CH_2CH_2Cl \qquad (II)$$

$$R = CH_3,\ C_2H_5\ \text{or}\ C_6H_5.$$
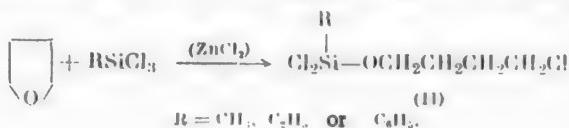
TABLE 1

Products of Reaction of Alkyl- and Arylchlorosilanes with Tetrahydrofuran in Presence of Zinc Chloride

Alkyl- and aryl-chlorosilanes	Amount of halo-silane (moles)	Amount of $ZnCl_2$ (g)	Reaction products and yields (in %)
CH_3SiHCl_2	1	2	1,4-Dichlorobutane (73)
$(CH_3)_2SiCl_2$	1	0.5	1,4-Dichlorobutane (68)
CH_3SiCl_3	1	0.5	1,4-Dichlorobutane (9), methyl-(δ-chlorobutoxy)--dichlorosilane (79)
$C_2H_5SiCl_3$	2	1	1,4-Dichlorobutane (12), ethyl-(δ-chlorobutoxy)--dichlorosilane (82)
$C_6H_5SiCl_3$	1	0.5	1,4-Dichlorobutane (4), phenyl-(δ-chlorobutoxy)--dichlorosilane (88)
$\begin{array}{c} C_2H_5 \\ | \\ Cl-Si-O(CH_2)_4Cl \\ | \\ Cl \end{array}$	0.37	0.2	1,4-Dichlorobutane (75)

In all cases, the reaction in the direction of formation of product (II) goes with high yields (80-90%) of mono(δ-chlorobutoxy)-dichlorosilanes.

Two of the chlorine atoms in mono(δ-chlorobutoxy)-dichlorosilane are active, but they react with tetrahydrofuran mainly in the direction of formation of 1,4-dichlorobutane:

$$\underset{O}{\boxed{}} + \underset{\underset{Cl\ Cl}{|\ |}}{R-Si-OCH_2CH_2CH_2CH_2} \longrightarrow \underset{\underset{Cl}{|}}{CH_2-CH_2-CH_2-CH_2} \quad \underset{Cl}{|}$$
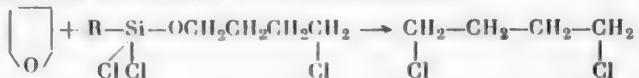
Evidently, the two chlorine atoms in $R_1R_2SiCl_2$, where R_1 and R_2 can be alkyl or alkoxy or a hydrogen atom, must be endowed with the special ability to cleave the tetrahydrofuran ring at both of the C—O bonds with formation of 1,4-dichloroalkane. This would explain why no appreciable quantities of di- and tri(δ-chlorobutoxy)--silanes are formed in the reaction of alkyl- and aryltrichlorosilanes with tetrahydrofuran.

EXPERIMENTAL

The tetrahydrofuran used in the work was isolated from the technical product, and after distillation it had b.p. 64° (753 mm), n_D^{20} 1.4079, and d_4^{20} 0.8876. Methyltrichlorosilane boiled at 63-65° (749 mm), ethyltrichlorosilane at 99-100°, phenyltrichlorosilane at 200°, methyldichlorosilane at 39-40°, and dimethyldichlorosilane at 69-70°.

Comparable results in the experiments on the study of reactions of tetrahydrofuran with halosilanes were ensured by operation under identical conditions by the following procedure.

Equimolar quantities of tetrahydrofuran and halosilane are placed in a flask fitted with a reflux condenser, and a small quantity of anhydrous zinc chloride (catalyst) is introduced. The reaction mixture is heated to the boil for 14 hours. Unchanged tetrahydrofuran and halosilane are removed by distillation, and the reaction products

TABLE 2

Chloro-Substituted Esters of Orthosilicic Acid of the Type of

$$R—SiCl_2$$
$$\searrow$$
$$O(CH_2)_4Cl$$
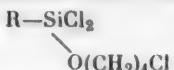
R	Boiling point (pressure in mm)	n_D^{20}	Found (%)				Calculated (%)			
			C	H	Cl	Si	C	H	Cl	Si
CH_3	49.5—50° (3), 205.5—206 (747)	1.4437	27.46	5.19	47.70	13.13	27.13	5.01	48.06	12.22
C_2H_5	104.5 (5), 114 (21), 224—225 (747)	1.4465	30.62	5.56	44.66	12.22	30.61	5.56	45.19	11.92
C_6H_5	299—301 (747)	1.5040	42.61	4.73	36.70	10.21	42.34	4.62	37.50	9.89

are fractionally distilled under reduced pressure in a glass-packed column. Hydrolysis of the resulting alkyl- or aryl-(δ-chlorobutoxy)-silanes gives 4-chloro-1-butanol with b.p. 80-81° (10 mm), $n^{20}D$ 1.4517 and d^{20}_4 1.0884.

Experimental conditions and yields of reaction products are set forth in Table 1.

The properties of the chloro-substituted esters of orthosilicic acid, now prepared by us for the first time, are set forth in Table 2.

These esters are colorless liquids with a pungent odor, distilling without decomposition at atmospheric pressure and easily soluble in common organic solvents.

SUMMARY

1. Reaction of tetrahydrofuran with alkyl- and arylchlorosilanes goes in different directions, depending on the number of chlorine atoms in the molecule of chlorosilane.

2. Dichlorosilanes cleave the tetrahydrofuran ring at both of the C—O bonds with formation of 1,4-dichlorobutane as the main product.

3. Reaction of tetrahydrofuran with alkyl- and aryltrichlorosilanes goes with opening of the ring mainly at one C—O bond with formation of the corresponding chloro-substituted esters of orthosilicic acid: alkyl- and aryl--(δ-chlorobutoxy)-dichlorosilanes.

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* Original Russian pagination. See C.B. translation.

SYNTHESIS OF 2-(3',4',5'-TRIMETHOXYBENZYL)-BENZIMIDAZOLE

N. I. Kudryashova, L. R. Davidenkov and N. V. Khromov-Borisov

Institute of Experimental Medicine, Academy of Medical Sciences, USSR

Certain alkaloids of pharmacological value (reserpine, mescaline, etc.), contain the 3,4,5-trimethoxyphenyl radical in their molecule. The role of this radical in the pharmacological activity of such compounds can be examined by a comparative study of already well-known therapeutic agents containing the phenyl radical on the one hand, and of similarly constituted compounds containing the 3,4,5-trimethoxyphenyl radical on the other hand.

In the present work, we describe the synthesis, and report some properties, of 2-(3',4',5'-trimethoxybenzyl)-benzimidazole (III), which is the trimethoxy derivative of the well-known therapeutic agent dibazol (2-benzyl-benzimidazole).

We found that 2-(3',4',5'-trimethoxybenzyl)-benzimidazole (III) is easily synthesized by condensation of o-phenylenediamine (I) with 3,4,5-trimethoxyphenylacetic acid (II):
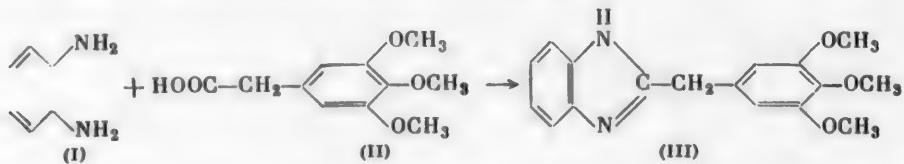
The most awkward problem in this connection is the preparation of acid (II). Although it was first described in 1893 [1], a convenient method of preparation of this acid has not hitherto been proposed.

We synthesized acid (II) by the following route:

$$H_3CO-\overset{\displaystyle H_3CO}{\underset{\displaystyle H_3CO}{\bigcirc}}-CH_2COOH$$

(II)
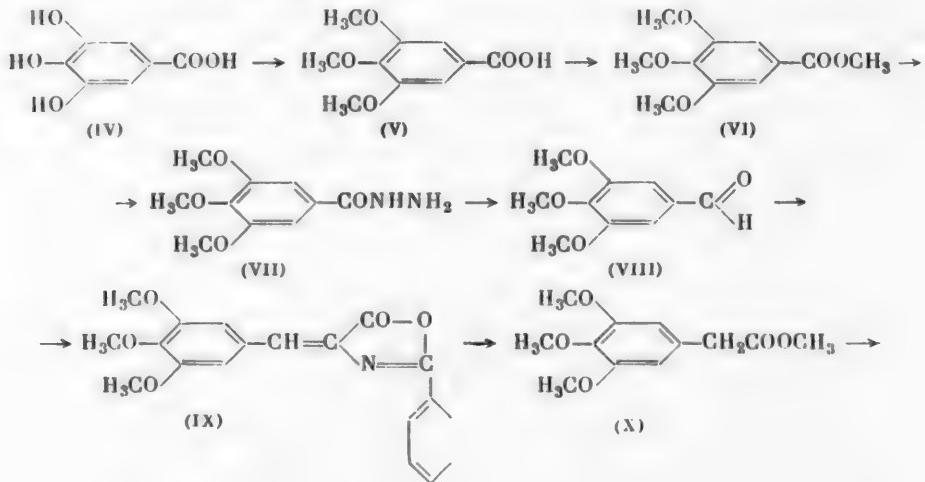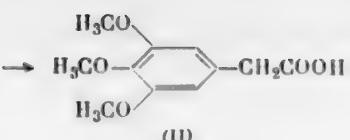
The starting substance was gallic acid (IV), which was methylated with dimethyl sulfate to give 3,4,5-tri-methoxybenzoic acid (V). The latter was converted to the methyl ester (VI) by heating in methyl alcohol in presence of sulfuric acid. The ester (VI) can also be obtained by passage of dry hydrogen chloride into a suspension of 3,4,5-trimethoxybenzoic acid in methyl alcohol [2]. The hydrazide of 3,4,5-trimethoxybenzoic acid (VII) was prepared from methyl ester (VI). Oxidation of the hydrazide with potassium ferricyanide gave 3,4,5-trimethoxy-benzaldehyde (VIII). Condensation of this aldehyde with hippuric acid led to the corresponding azlactone (IX). The next three operations of hydrolysis, oxidation with hydrogen peroxide and esterification were effected without isolation of intermediate products. The resulting mixture of methyl esters of 3,4,5-trimethoxyphenylacetic and benzoic acids was easily fractionated in vacuo. Saponification of the methyl ester of trimethoxyphenylacetic acid gave 3,4,5-trimethoxyphenylacetic acid.

3,4,5-Trimethoxyphenylacetic acid can also be obtained via hydrolysis of the azlactone and isolation of trimethoxyphenylracemic acid in the form of the water-soluble bisulfite derivative. Trimethoxyphenylracemic acid was isolated from the latter and oxidized with hydrogen peroxide to trimethoxyphenylacetic acid, but the yield is very much lower than by the first variant.

Although our proposed synthesis of 3,4,5-trimethoxyphenylacetic acid also has many steps, each of them goes very smoothly, and difficultly accessible reagents are not required. In the development of this method, we successfully made use of several techniques that were used in the synthesis of 3,4-dimethoxyphenylacetic acid [3].

Condensation of 3,4,5-trimethoxyphenylacetic acid with o-phenylenediamine goes smoothly when equimolar quantities of the components are heated at 180°. We failed to obtain 2-(3',4',5'-trimethoxybenzyl)-benzimidaz-ole by the method of A. Phillips, i.e., by many hours' boiling of a mixture of 3,4,5-trimethoxyphenylacetic acid, o-phenylenediamine, and 15% hydrochloric acid. Under these conditions, the formation of the imidazole ring evidently goes concomitantly with hydrolysis of the methoxy groups, and a mixture of benzimidazoles with meth-oxy and hydroxy groups is formed which we were unable to fractionate.

A preliminary pharmacological examination of 2-(3',4',5'-trimethoxybenzyl)-benzimidazole by O. D. Kozlov showed that it resembled dibasol in possessing a certain hypotensive and spasmolytic activity.

EXPERIMENTAL

Methyl 3,4,5-trimethoxybenzoate (VI). 3,4,5-Trimethoxybenzoic acid was prepared from gallic acid by the literature method [4].

A mixture of 56.5 g of this acid, 420 ml methyl alcohol, and 17 ml concentrated H_2SO_4 was refluxed 1.5 hr. The still-warm liquid was carefully neutralized with a solution of 50 g sodium carbonate in 400 ml water. After cooling, the resulting crystals were collected, washed with water, and dried. Yield 48.5 g (80.5%), m.p. 81-83°.

Hydrazide of 3,4,5-trimethoxybenzoic acid (VII). The literature method [5] was used for the preparation. A mixture of 25.7 g methyl ester of trimethylgallic acid, 13.8 ml 90% hydrazine hydrate, 13.8 ml water, and 46 ml methyl alcohol was gently refluxed in a flask for 2 hrs. After cooling, the crystals were filtered, washed 2-3 times with cold water, and dried. Yield 22.1 g (85.5%), m.p. 128-130°.

3,4,5-Trimethoxybenzaldehyde (VIII). 29.6 g hydrazide of 3,4,5-trimethoxybenzoic acid, 595 ml water, and 65 ml 24% ammonia were placed in a three-necked flask. A solution of 157 g potassium ferricyanide in 700 ml water was gradually stirred in. Stirring was continued for 30 min after the addition. The precipitate was filtered and washed with water. The filtrate was extracted 3 times with ether and the ethereal extract was washed with 3% hydrochloric acid, with water, and with 5% sodium carbonate solution. The ether was driven off and the residue was poured into a crystallizer where it crystallized quickly when cooled. Yield 13.8 g (53.8%), m.p. 71-73°.

Azlactone (IX). This is very easily prepared by the method proposed for preparation of the azlactone of veratraldehyde [6]. 13.6 g of 3,4,5-trimethoxybenzaldehyde, 13.4 g hippuric acid, 5.57 g fused sodium acetate,

and 19.6 ml acetic anhydride were thoroughly stirred and heated on an electric hotplate until solution was complete; the solution acquired an orange color. The mixture was then heated 2 hr on a water bath. At the end of this period, 29 ml alcohol was added and the mass left overnight. Orange crystals came down and were filtered, washed with hot water, and dried. Yield 15.45 g (70.5%), m.p. 161-164°.

Methyl 3,4,5-trimethoxyphenylacetate (X) was prepared by a method similar to that for the preparation of the methyl ester of homoverartric acid [3]. 15.4 g azlactone and 70 ml 10% sodium hydroxide solution were refluxed in a flask for 6 hrs. The flask was thereupon cooled with a mixture of ice and salt; 6 ml 40% sodium hydroxide solution was added, and 11 ml 15% hydrogen peroxide was gradually run in dropwise. The reaction mixture was worked up as in the preparation of the methyl ester of homoveratic acid [3]. Yield 4.4 g (40%), m.p. 139-140° (1 mm) [7].

3,4,5-Trimethoxyphenylacetic acid (II). Methyl 3,4,5-trimethoxyphenylacetate (4.1 g) was saponified by cautious refluxing with 13 ml 10% sodium hydroxide solution. The resulting solution was poured into a mixture of 6.5 ml concentrated hydrochloric acid and 18 g ice. After standing for half an hour, the precipitate was filtered. Yield nearly quantitative. M.p. 119-121° after recrystallization from a mixture of benzene and ligroine (2:1).

2-(3',4',5'-Trimethoxybenzyl)-benzimidazole (III) hydrochloride. 1.5 g of 3,4,5-trimethoxyphenylacetic acid and 0.93 g twice recrystallized o-phenylenediamine were placed in a test tube and heated on a bath of Wood's alloy at 180° for 15 min (until water ceased to come off). The hot, liquid melt (colored violet) was then poured into 40 ml dilute hydrochloric acid (1:4). Crystals came down and were filtered, recrystallized from 15 ml water (containing active carbon), and again recrystallized from 10 ml water. Yield 1.5 g (68.1%), m.p. 194-198°.

Found %: N 8.23, 8.12. $C_{17}H_{18}O_3N_2HCl$.

Calculated %: N 8.37.

SUMMARY

1. A laboratory method for preparation of 3,4,5-trimethoxyphenylacetic acid was presented.

2. 2-(3',4',5'-Trimethoxybenzyl)-benzimidazole, not previously described in the literature, was synthesized.

3. The synthesized preparation was found to possess hypotensive and spasmolytic activity.

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UNSYMMETRICAL α-OXIDES

PREPARATION AND PROPERTIES OF UNSYMMETRICAL METHYLISOPROPYL ETHYLENE AND METHYL-TERT-BUTYLETHYLENE OXIDES

M. S. Malinovskii and A. G. Yudasina

Dnepropetrovsk State University

Original article submitted May 20, 1958

A study is made of the susceptibility to hydration, isomerization, and hydroxyamine formation of unsymmetrical α-oxides.

Several authors [1] have established that the hydration of aliphatic α-oxides containing a tertiary carbon atom in the oxide ring goes very energetically.

Investigation of methylisopropyl ethylene oxide (I) and methyl-tert-butylethylene oxide (II), which we prepared, revealed that they easily isomerize to aldehyde even during heating or distillation, but their hydration goes with difficulty:
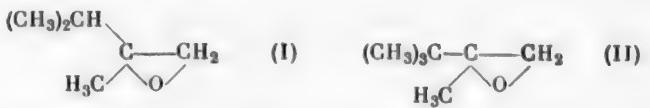
The main products of hydration of these oxides are their isomeric aldehydes. A similar phenomenon was observed by Pansevich-Kolyada [2,3] in the case of 1,1-diphenylpropene oxide, 1-phenyl-2-butene oxide, and 2-phenyl-2-butene oxide. Hydration of the first of these gives a ketone in addition to a glycol; in presence of alcohol the second entirely isomerizes to 2-phenylbutanone.

Many investigators [4] have mentioned the great susceptibility to isomerization of unsymmetrical olefinic α-oxides.

On the basis of our experimental material and of literature data, we can infer that the presence of a large number of electron-donating substituents so polarizes the molecule of the oxide that its most highly hydrogenated carbon atom becomes more positive; this facilitates the migration of a hydrogen atom to a neighboring carbon atom at which there is a higher electronic density.

In this connection, special interest is attached to methyl-tert-butylethylene oxide (which we prepared for the first time). The association of two tertiary carbon atoms in the oxide molecule evidently imparts lability to the compound. In the very process of synthesis (and, possibly also, of distillation) a relatively large quantity of polymeric products is formed, due to which the yield of oxide is small. Reaction of the oxide with diethylamine with the aim of preparation of the hydroxyamine also leads mainly to formation of polymers. Isomerization of oxide (II) occurs under the usual conditions of hydration of aliphatic oxides.

We succeeded in obtaining a good yield of hydroxyamine from methylisopropyl ethylene oxide. This oxide likewise isomerizes readily, but hydration also leads to the glycol in addition to aldehyde. It should be noted that oxide (I) also possesses electron-donating radicals, just like oxide (II), but in smaller number; it therefore undergoes a series of reactions characteristic of the oxide ring. We must evidently agree with Martynov's conclusion [5] that "substituents possessing a high electron-donating capacity render the oxide ring very unstable."

We also tried to prepare oxide (II) by oxidation of the corresponding unsaturated hydrocarbon with benzoyl hydroperoxide. This reaction gave, in place of the oxide, the glycol monobenzoate (III) or (IV):

$$(CH_3)_3C \diagdown C \diagup CH_2OH \quad (CH_3)_3C \diagdown C \diagup CH_2OCOC_6H_5$$
$$CH_3 \mid OCOC_6H_5 \quad\quad CH_3 \mid OH$$
$$(III) \quad\quad\quad\quad (IV)$$
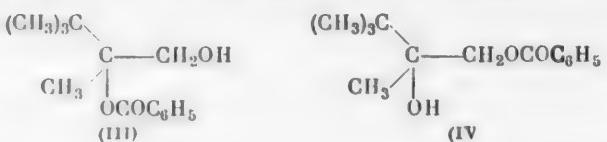
Formula (III) is the more probable, as demonstrated by formation of iodoform.

It may be suggested that the glycol monobenzoate is formed from the hydrocarbon by the following sequence of reactions:

$$(CH_3)_3C \diagdown C=CH_2 \xrightarrow{C_6H_5COOOH} (CH_3)_3C \diagdown C \underset{O}{----} CH_2 \xrightarrow{C_6H_5COOH} (CH_3)_3C \diagdown C \diagup CH_2OH$$
$$CH_3 \quad\quad\quad\quad CH_3 \quad\quad\quad\quad CH_3 \mid OCOC_6H_5$$
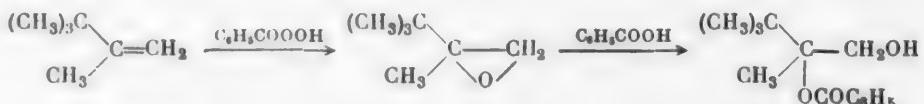
In this connection, we may recall that Tiffeneau and Kuriaki [6] oxidized unsymmetrical diphenylethylene by Prilezhaev's method and obtained, instead of the expected oxide, diphenylethylene glycol benzoate, together with other products. Stevens and Tazuma [7] oxidized 1-ethoxy-1-cyclohexene with benzoyl hydroperoxide, and obtained α-hydroxycyclohexanone benzoate.

EXPERIMENTAL

Oxides were prepared from the corresponding halohydrins by the action of excess of potassium hydroxide. Halohydrins were synthesized by the Grignard reaction from chloroacetone (or bromoacetone).

Synthesis of 2,3-dimethyl-4-chloro-3-butanol. This substance was obtained by the usual procedure from 58 g magnesium, 208 g isopropyl bromide (dissolved in 400 ml ether) and 130 g chloroacetone (dissolved in 300 ml ether). Yield of crude chlorohydrin 51 g (27.9%); yield of pure substance 30 g.

B.p. 45-46° (3-5 mm), d^{20}_4 1.0378; n^{20}D 1.449.

Found %: Cl 26.45. $C_6H_{13}OCl$.

Calculated %: Cl 25.98.

Synthesis of 2,3-dimethyl-4-bromo-3-butanol. The bromohydrin was prepared from 28 g magnesium, 123 g isopropyl bromide, and 110 g bromoacetone by the usual procedure. It decomposed when distilled in vacuo (10 mm). In later experiments the crude bromohydrin was worked up to oxide.

Synthesis of unsymm. methylisopropylethylene oxide. Pulverized potassium hydroxide was gradually added to an ethereal solution of the chlorohydrin or bromohydrin. The ethereal solution was worked up to give 18.2 g crude oxide from which 3 fractions were obtained by fractionation: 1st, 45-50° (70 mm), 1 g; 2nd, 50-52° (70 mm), 10 g; 3rd, 61-65° (70 mm), 2 g.

The 3rd fraction was the aldehyde to which the oxide had isomerized. This fraction gave all of the characteristic reactions for aldehydes. The 2nd fraction was oxide (II), which had a camphor-like odor.

B.p. 50-52° (70 mm), d^{20}_4 0.834, n^{20}D 1.401, MR_D 29.13; calc. 29.93.

Found %: C 72.25, 72.30; H 12.0, 11.75. M 100. $C_6H_{12}O$.

Calculated %: C 71.93; H 12.09. M 100.

The presence of the oxide ring was confirmed by reaction with potassium iodide [8], as well as by isomerization and formation of the corresponding hydroxyamine.

Synthesis of 2,2,3-trimethyl-4-chloro-3-butanol was effected in the usual manner from 65 g magnesium, 170 g tert-butyl chloride (mixed with 500 ml ether) and 135 g chloroacetone. There was obtained 80 g crude chlorohydrin which decomposed when distilled in vacuo (0.3 mm) and rapidly darkened on standing. It was therefore usually not isolated from the ethereal solution, but at once worked up to oxide.

Synthesis of methyl-tert-butylethylene oxide was effected by the above procedure from 80 g crude chloro-hydrin and 135 g potassium hydroxide. After the ether had been driven off, the residue of 35 g liquid was frac-tionated at 50 mm: 1st, 45-55°, 5 g; 2nd, 55-100°, quantity insignificant; 3rd, 100-110°, 11 g; residue 12.2 g. Redistillation of the 1st fraction gave about 4 g of liquid.

B.p. 48-51° (55 mm), d^{20}_4 0.830, n^{20}D 1.4160, MR_D 34.20; calc. 34.55.

Found %: C 73.21, 73.28; H 12.00, 12.10. M 115.1. $C_7H_{14}O$.

Calculated %: C 73.63; H 12.37. M 114.

The 3rd fraction, after redistillation in vacuo, was an oily liquid which turned faint-yellow on standing. B.p. 77-78° (10 mm), n^{10}D 1.4565.

Found %: C 72.20; H 11.30. M 242. $C_{14}H_{28}O_2$.

Calculated %: C 73.63; H 12.37. M 228.

Reaction of oxides (I) and (II) with water. 5-6 ml water was added to 2 g oxide and hydrogen chloride was passed through for 1 min. The reaction mixture was then shaken 6 hr at room temperature. The glycol was ex-tracted with ether, dried with sodium sulfate, and distilled.

Oxide (I) gave unsymm. methylisopropylethylene glycol with b.p. 194-197°, d^{20}_4 0.980, n^{20}D 1.4410. The properties correspond to those of a similar glycol described in the literature [9].

Under the above conditions, oxide (II) isomerized to the aldehyde.

Isomerization of the oxides. Agents such as zinc chloride and sulfuric acid (1 and 10%) polymerize oxides (I) and (II); isomerization was therefore effected in presence of one drop of 3% sulfuric acid. The reaction products were quickly distilled with steam and extracted with ether; the ethereal solution was dried with sodium sulfate, the ether was driven off, and the residue was distilled at atmospheric pressure. The following fractions were col-lected during distillation of the products of isomerization of 2.3 g oxide (I): 1st, 116-120°, 0.4 g; 2nd, 120-178°, 0.3 g; residue 1 g. The 1st fraction gives all of the qualitative reactions for aldehydes.

From 2.0 g oxide (II) was obtained a fraction with b.p. 138-140° (0.4 g), which gave all of the aldehyde reactions. A considerable amount of material did not distill, but resinified.

Addition of diethylamine to oxides (I) and (II). An ampoule was charged with 2.5 g oxide, 5 g diethylamine, and a few drops of water. The sealed ampoule was heated 3 hr on a boiling water bath. Unreacted diethylamine was taken off on a water bath, and the hydroxyamine was distilled in vacuo.

The hydroxyamine from (I) had the following constants:

B.p. 106-108° (20 mm), d^{24}_4 0.873, n^{24}D 1.4386, MR_D 51.17; calc. 50.71.

Found %: N 8.58. M 169. $C_{10}H_{23}ON$.

Calculated %: N 8.23. M 170.

Oxide (II) was reacted with diethylamine at the same temperature but with replacement of the water by methanol, and with prolongation of the heating period to 20 hr. Fractional distillation of the reaction mixture led mainly to separation of unreacted oxide; only a few drops of liquid with b.p. 80° (10 mm) were obtained (ni-trogen was detected by qualitative test).

Preparation of oxide (II) by oxidation with benzoyl hydroperoxide. 2,2,3-Trimethyl-3-butene, prepared by dehydration of 2,2,3-trimethyl-3-butanol, was subjected to oxidation. The tertiary alcohol was synthesized by the Grignard reaction from tert-butyl chloride and acetone. The alcohol boiled at 130-132° [10].

The alcohol was dehydrated by slow heating in a Wurtz flask on a water bath in presence of a few crystals of iodine. The resulting unsaturated hydrocarbon was quickly distilled and dried with calcium chloride; b.p. 78 to 80° [11]. Attempted dehydration of the carbinol with sulfuric acid led to polymer formation.

Oxide (II) was prepared from the hydrocarbon by the Prilezhaev method in chloroform [12]. After 5 hr, analysis [13] revealed traces of unreacted hydroperoxide. The usual working-up gave 2 g substance with b.p. 100 to 101° (45 mm); the product was a liquid with a pleasant odor.

B.p. 191-192°, n^{19}D 1.5162, d^{19}_4 1.0718.

Found %: C 70.52; H 7.92. M 250, 247. $C_{14}H_{20}O_3$.

Calculated %: C 71.18; H 8.46. M 236.

The analysis and constants of the substance do not correspond to those of oxide (II). Saponification of the substance with 0.5 N potassium hydroxide solution in the cold or with heating gave benzoic acid in quantity nearly equivalent to the monoether. No depression of m.p. in admixture with authentic benzoic acid.

SUMMARY

1. Unsymm. methylisopropylethylene oxide and methyl-tert-butylethylene oxide were synthesized from the corresponding halohydrins and characterized.

2. Oxidation with benzoyl hydroperoxide of 2,2,3-trimethyl-3-butene gave the glycol monobenzoate instead of the α-oxide. The above two oxides, especially the second one, are very easily isomerized to aldehydes.

3. The corresponding hydroxyamine was obtained by reaction of diethylamine with methylisopropylethylene oxide.

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*Original Russian pagination. See C.B. translation.

THE SULFONATION OF β-DIKETONES

VI. DERIVATIVES OF 1,3-INDANEDIONE-2-SULFONIC ACID*

E. Gudrinietse, G. Vanag, A. Strakov and O. Neiland

Latvian State University

Original article submitted May 19, 1958

There are no literature data for derivatives of the keto group of sulfonic acids of ketones and aldehydes [1]. Although the preparation of the dioxime of 1,3-indanedione-2-sulfonic acid from the dipotassium salt of the acid by treatment with hydroxylamine hydrochloride in presence of potassium carbonate has been described [2], we were unable to repeat these experiments either with the disodium or the dipotassium salts of this acid. The original substance, and not the dioxime in question, came down when alcohol was added.
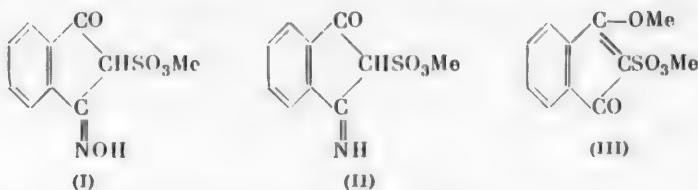
Our investigations have shown that oxime (I) is easily formed by boiling the sodium salt of 1,3-indanedione--2-sulfonic acid in glacial acetic acid with hydroxylamine hydrochloride in presence of anhydrous sodium acetate, or in absence of the latter (in alcohol). The oxime that we obtained was white and poorly soluble in water (1 g in 100 ml). Bromination gave 2,2-dibromo-1,3-indanedione.

Derivatives of 1,3-indanedione are known to react easily with ammonium acetate in glacial acetic acid [3-6] to form the corresponding ketimines. It was found that under similar conditions, the oxygen of the keto group of the sodium salt of 1,3-indanedione-2-sulfonic acid is also substituted by the imino group. The product is the yellow-orange ammonium salt of the imine of 1,3-indanedione-2-sulfonic acid (II) (Me = NH_4). Proof that this was not the diammonium salt of acid (III) (Me = NH_4) was obtained by preparation of the disodium salt of imine (IV) (Me = Na) by treatment of imine (II) (Me = NH_4) with an alcoholic solution of sodium hydroxide or sodium ethoxide. Evidently, the structure of the salts of the imine of 1,3-indanedione-2-sulfonic acid (II) is similar to that of the imine of 2-phenyl-1,3-indanedione,** i.e., the enaminic inner salt of the ketoenol (V) is formed:
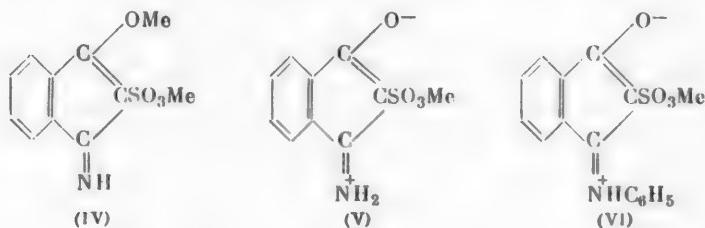
* Preceding communication in Proc. Higher School of Chem. and Chem. Tech. 1958, 746.

** The structure of the imine of 2-phenyl-1,3-indanedione was recently clarified by G. Vanag and Ya. Freimanis, whose work will be the subject of a separate paper.
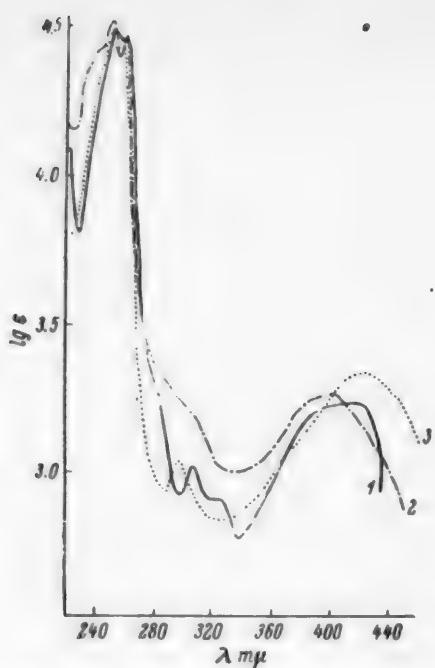
Ultraviolet absorption spectra: 1) ammonium salt of the imine of 1,3-indanedione-2-sulfonic acid in aqueous solution; 2) disodium salt of 1,3-indanedione-2-sulfonic acid in aqueous solution; 3) 1,3-indanedione in 2 N NaOH.

In connection with the proposed structure of the imine of 1,3-indanedione-2-sulfonic acid, ultraviolet absorption spectra were plotted for the imine and for the disodium salt of 1,3-indanedione-2-sulfonic acid in water, and for 1,3-indanedione in alkaline solution. The absorption maxima of 249 mμ (log ε 4.53) and 259 mμ (log ε 4.48) of the disodium salt of 1,3-indanedione-2--sulfonic acid are close to the maximum of 251 mμ (log ε 4.505) in the inflection in the 260 mμ region for the imine. Comparison with the absorption curve of 1,3--indanedione in alkali solution reveals that the sulfo group in the 2-position causes only a very small bathochromic shift: 248 mμ (log ε 4.49); 255 mμ (log ε 4.47).

The observed absorption maxima of the disodium salt of 1,3-indanedione-2-sulfonic acid and of 1,3-indanedione in alkali solution evidently characterize the enolate form of these compounds. The imine should therefore possess the enolate structure (V). Consequently, the absorption spectra support the bipolar structure of the imine.

The aniline salt of the phenylimine of 1,3-indanedione-2-sulfonic acid (VI) (Me = phenylammonium) and the disodium salt of the phenylimine of 1,3-indanedione--2-sulfonic acid (VII) (Me = Na) were similarly prepared. On bromination, the phenylimine and the imine split off the imino, or the phenylimino, and the sulfo groups, and form 2,2-dibromo-1,3-indanedione:

(VII)

(VIII)
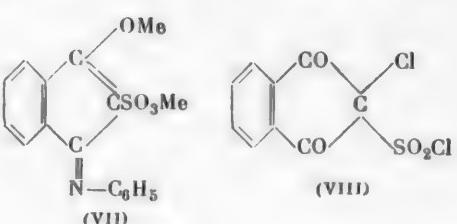
The sodium salt of 1,3-indanedione-2-sulfonic acid easily forms a light-brown semicarbazone. It also reacts with phenylhydrazine; the reaction is fairly complex and will be the subject of a separate publication.

Treatment of the dry sodium salt of 1,3-indanedione-2-sulfonic acid with phosphorus pentachloride gave 2-chloro-1,3-indanedione-2-sulfochloride (VIII) in the form of yellow crystals. It is interesting to note that the hydrogen of the active methylene group is not replaced by chlorine when 1,3-indanedione itself is treated with phosphorus pentachloride [7].

We know that heating of fluorenyl-9-sulfochloride [8], DL-camphor-π-sulfochloride [9], and β-bromocamphor-α-sulfochloride [10] leads to removal of sulfur dioxide and formation of chloro derivatives. 1,3-Indanedione--2-sulfochloride (VIII) reacts similarly. It splits off sulfur dioxide on heating and forms 2,2-dichloro-1,3-indanedione. This interesting reaction has not previously been noted in the literature; it is merely reported [9,10] that sulfur dioxide splits off from sulfochlorides only at high temperatures. Further investigations will show whether this reaction is general for all sulfochlorides of β-diketones.

EXPERIMENTAL

Monoxime of the sodium salt of 1,3-indanedione-2-sulfonic acid (I) (Me = Na). A mixture of 1.4 g sodium salt of 1,3-indanedione-2-sulfonic acid, 0.7 g hydroxylamine hydrochloride, 1.3 g anhydrous sodium acetate, and

10 ml glacial acetic acid was refluxed 20-25 min in a round-bottomed flask. At first, the solution was yellow, but it quickly lost its color and deposited the white sodium salt of the oxime of 1,3-indanedione-2-sulfonic acid (I) (Me = Na). The monoxime is formed in good yield in ethanol and in the absence of sodium acetate. It can be recrystallized from a larger volume of water. It is preferably not recrystallized, but washed well with water. There was obtained 1.2 g (75%) of fine, white crystals. Insoluble in organic solvents, but soluble in hot water (1 g in 100 ml water) with a yellowish color. It forms a yellow solution in alkalies.

Found %: Na 8.69; N 5.48. $C_9H_6O_5NSNa$.

Calculated %: Na 8.74; N 5.32.

Disodium salt of the oxime of 1,3-indanedione-2-sulfonic acid. 1 g sodium salt of oxime of 1,3-indane-dione-2-sulfonic acid and 20 ml anhydrous alcohol were put in a small round-bottomed flask fitted with a con-denser, and 0.5 ml metallic sodium was gradually added. When the sodium had reacted, heating was continued for another 5 min. The precipitate was recrystallized from a small amount of dilute alcohol. The yellow di-sodium salt of the oxime of 1,3-indanedione-2-sulfonic acid came down slowly. Very soluble in water. The aqueous solution has an alkaline reaction to litmus. Poorly soluble in organic solvents.

Found %: Na 16.60; N 4.80. $C_9H_5O_5NSNa_2$.

Calculated %: Na 16.14; N 4.91.

Bromination of the sodium salt of the oxime of 1,3-indanedione-2-sulfonic acid (I) (Me = Na). A mixture of 1.3 g sodium salt of the monoxime of 1,3-indanedione-2-sulfonic acid (I) (Me = Na), 30 ml glacial acetic acid, and 1 ml bromine was stood 1 hr at room temperature. 2,2-Dibromo-1,3-indanedione was obtained after dilution with water. From glacial acetic acid it came down as colorless needles with m.p. 174-175°. A mixture with authentic 2,2-dibromo-1,3-indanedione melted without depression.

Ammonium salt of the imine of 1,3-indanedione-2-sulfonic acid (II) (Me = NH_4). 15 g ammonium acetate was dissolved in 12 ml glacial acetic acid in a round-bottomed flask fitted with a reflux condenser. To the hot solution was added 3 g sodium salt of 1,3-indanedione-2-sulfonic acid and the mass was heated for a further 15 min. The solution became dark-yellow, and on cooling it solidified to a crystal mass which was treated 3-4 times with 60% ethyl alcohol in the cold. The insoluble brown solid was recrystallized from 60% ethyl alcohol. There was obtained 1.8 g (58%) ammonium salt of the imine of 1,3-indanedione-2-sulfonic acid (II) (Me = NH_4) in the form of fine yellow prisms with m.p. 240° (decomp.). Readily soluble in water and glacial acetic acid, poorly soluble in methanol and ethanol, insoluble in ether and nonpolar solvents.

Found %: N 11.53. $C_9H_{10}O_4N_2S$.

Calculated %: N 11.57.

Disodium salt of the imine of 1,3-indanedione-2-sulfonic acid (IV) (Me = Na). 0.8-0.9 g metallic sodium was slowly added to a solution of 2.4 g ammonium salt of imine (V) (Me = NH_4) in 30 ml anhydrous alcohol. Am-monia came off and a yellow precipitate was formed. Recrystallization from 40% ethyl alcohol gave 2.2 g (80%) disodium salt of the imine of 1,3-indanedione-2-sulfonic acid (IV) (Me = Na). This salt is also obtained from an alkaline solution of the ammonium salt of imine (V) (Me = NH_4) by addition of alcohol. Readily soluble in water, less soluble in glacial acetic acid, nearly insoluble in alcohol, m.p. 280° (decomp.).

Found %: Na 17.30; N 5.30. $C_9H_5O_4NSNa_2$.

Calculated %: Na 17.10; N 5.20.

Bromination of the ammonium salt of the imine of 1,3-indanedione-2-sulfonic acid. A mixture of 30 ml glacial acetic acid, 1.2 g ammonium salt of imine of 1,3-indanedione-2-sulfonic acid, and 0.5 ml bromine was stood 2 hr at room temperature. The mass was then diluted with 50 ml water. The resulting precipitate was re-crystallized from glacial acetic acid to give 1.3 g 2,2-dibromo-1,3-indanedione with m.p. 175-176°. A mixture with authentic 2,2-dibromo-1,3-indanedione melted without depression.

Aniline salt of the phenylimine of 1,3-indanedione-2-sulfonic acid (VI) (Me = phenylammonium). 2.5 g sodium salt of 1,3-indanedione-2-sulfonic acid, 10 ml aniline, and 10 ml glacial acetic acid were heated 2 hr on a water bath. The red aniline salt of the phenylimine came down after 3-4 hr. Recrystallization from ethanol

gave 2.3 g (70%) of yellowish needles of (VI) (Me = phenylammonium). The product was soluble in alcohol and glacial acetic acid, poorly soluble in water and acetone, insoluble in benzene; m.p. 160-162° (decomp.). The same product is obtained by treatment of the potassium and aniline salts of 1,3-indanedione-2-sulfonic acid.

Found %: N 7.83. $C_{21}H_{18}O_4N_2S$.

Calculated %: N 7.77.

Disodium salt of 1,3-indanedione-2-sulfonic acid phenylimine (VII) (Me = Na) was obtained in similar fashion to the disodium salt of 1,3-indanedione-2-sulfonic acid imine (IV) (Me = Na). It formed yellow prisms after recrystallization from 40% ethyl alcohol; m.p. 290° (decomp.).

Found %: Na 13.50; N 3.60. $C_{15}H_9O_4NSNa_2$.

Calculated %: Na 13.33; N 4.05.

Sodium salt of 1,3-indanedione-2-sulfonic acid semicarbazone. 1.4 g sodium salt of 1,3-indanedione-2--sulfonic acid, 1 g semicarbazide hydrochloride, and 1.3 g anhydrous sodium acetate in 30 ml glacial acetic acid were boiled 30 min. A brown precipitate came down on cooling. It was recrystallized from 60% alcohol to give 1.3 g (86%) of fine, brown crystals of the sodium salt of 1,3-indanedione-2-sulfonic acid semicarbazone. Soluble in water, less soluble in glacial acetic acid, almost insoluble in alcohol, acetone, benzene, and ether; m.p. 280 to 283° (decomp.).

Found %: N 14.15. $C_{10}H_8O_5N_3SNa$.

Calculated %: N 13.77.

1,3-Indanedione-2-sulfochloride. 5 g anhydrous sodium salt of indanedione sulfonic acid, dried at 110°, and 16 g phosphorus pentachloride were heated 2 hr on a water bath; after cooling, the mass was poured onto ice. The crude sulfochloride (VIII) was recrystallized from benzene, chloroform, or carbon tetrachloride to give yellowish prisms, readily soluble in benzene, less-readily soluble in carbon tetrachloride and chloroform, insoluble in water and ether; m.p. 98-99°.

Found %: Cl 25.58. $C_9H_4O_4SCl_2$.

Calculated %: Cl 25.70.

Bromination of 1,3-indanedione-2-sulfochloride. A mixture of 15 ml glacial acetic acid, 1.4 g 1,3-indanedione-2-sulfochloride, and 1.3 g dioxane dibromide was stood 1 hr at room temperature and then diluted with 15-20 ml water. The precipitate was recrystallized from ethanol to give white plates of 2-chloro-2-bromo-1,3--indanedione with m.p. 141-143° (literature [11]: m.p. 147°).

Reaction of 1,3-indanedione-2-sulfochloride (VIII) with alcohols. 1.4 g of (VIII) was heated with 10 ml ethanol on a water bath. The chloride dissolved and sulfur dioxide was evolved. When the latter had ceased to come off, 15 ml hot water was added. Within a few minutes, lustrous plates of 2,2-dichloro-1,3-indanedione [11] came down; m.p. 123-124°. A mixture with authentic 2,2-dichloro-1,3-indanedione melted without depression.

A similar reaction course is followed with methyl, propyl, isopropyl, and n-butyl alcohols. 2,2-Dichloro--1,3-indanedione is obtained in 80% yield.

SUMMARY

The oxime, semicarbazone, imine, and phenylimine of 1,3-indanedione-2-sulfonic acid were prepared in the form of the sodium, ammonium, and aniline salts.

Bromination of the sodium salt of the oxime of 1,3-indanedione-2-sulfonic acid, and of the ammonium salt of the imine of the acid gives 2,2,-dibromo-1,3-indanedione.

Phosphorus pentachloride acts on the sodium salt of 1,3-indanedione-2-sulfonic acid to give 1,3-indanedione--2-sulfochloride. Its bromination gives 2-chloro-2-bromo-1,3-indanedione. The sulfochloride loses sulfur dioxide when boiled with alcohols, and is converted into 2,2-dichloro-1,3-indanedione.

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TERTIARY TRIHYDRIC ALCOHOLS OF THE ACETYLENIC SERIES AND THEIR TRANSFORMATIONS

XII. THE HYDRATION OF 3,4,7-TRIMETHYL-5-NONYNE-3,4,7-TRIOL

V. I. Nikitin and A. B. Zegel'man

Institute of Chemistry, Academy of Sciences, Tadzhik SSR

Original article submitted May 31, 1957

Work carried out in recent years in our institute on the synthesis and transformations of tertiary glycerols of the acetylenic series prompted us to make a study of the Kucherov reaction in this series of compounds.

We know from the literature that the Kucherov reaction [1] does not, in all cases, lead only to simple hydration of the triple bond [2-20].

In the present paper, we describe the hydration of 3,4,7-trimethyl-5-nonyne-3,4,7-triol (I) since it is precisely in this case that we have succeeded in isolating several intermediate products, and have gained an insight into the fairly complex mechanism of the transformations here taking place. Hydration was effected by the method of Scheibler and Fischer [16], but at different temperatures. We established that the initial addition of water at the triple bond gives rise, in this class of compounds, to a series of consecutive reactions.

The mechanism of the transformations that take place here can be represented by the following scheme:

Transformations During Hydration of 3,4,7-Trimethyl-5-Nonyne-3,4,7-Triol
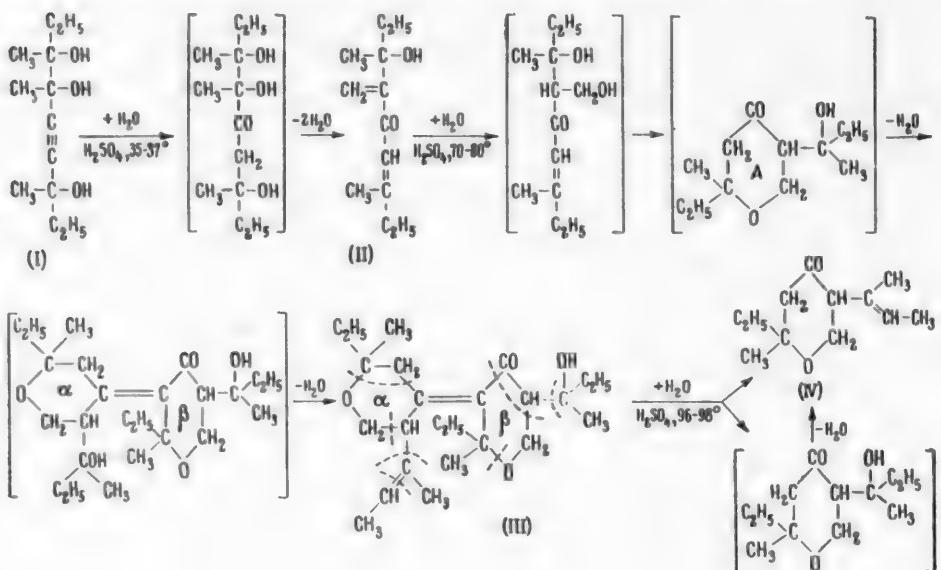
The acetylenic triol (I) hydrates to a ketotriol, which loses two molecules of water to form a dienic keto-alcohol — 3,7-dimethyl-4-methylene-3-hydroxy-6-nonen-5-one (II). The latter can be isolated from the reaction products if hydration is performed at a temperature not higher than 30-40°. The structure of (II) was confirmed by oxidation with potassium permanganate to methyl ethyl ketone and formic, oxalic, and α-methyl-α--hydroxybutyric acid.

Reaction at a higher temperature (70-80°) results in addition of water to (II). As often observed by I. N. Nazarov [21] with other compounds, this addition takes place at the unsubstituted double bond to form a primary alcoholic group. The resulting primary-tertiary ketoglycol at once cyclizes to the substituted tetrahydro-γ-pyrone. This cyclization can go in two directions: either the primary alcohol group participates in formation of the pyrone ring, in which case the side chain of the pyrone will contain sec-hydroxybutyl (form A), or the pyrone ring is formed at the expense of the tertiary hydroxyl group, and then the resulting tetrahydro-γ-pyrone will contain a primary hydroxyl.

We believe that cyclization goes in the direction of formation of product (A). This assumption is based on the fact that the product of further condensation of (A) — compound (III) — is recovered unchanged when its oxidation is attempted with Beckmann's reagent [22] (chromic acid mixture), whereas a primary alcoholic group is bound to be oxidized to the corresponding aldehyde. The proposed mechanism is fully confirmed by formation of acetic acid (among other products) when (III) is oxidized with potassium permanganate.

Two molecules of substituted tetrahydro-γ-pyrone, formed from the dienic ketoalcohol (II) by the cyclohydration just discussed, undergo crotonic condensation with loss of 1 molecule of water. In the hydration of other acetylenic triols (see the next paper), this product of crotonic condensation is easily isolated, but in the present case it undergoes partial dehydration and forms 2-methyl-2-ethyl-5-sec-butenyltetrahydropyranylidene-2'--methyl-2'-ethyl-5'-sec-hydroxybutyltetrahydro-γ-pyrone (III). The structure of (III) follows from all of the experimental data that we obtained, and it is confirmed by oxidation with potassium permanganate when the following products are isolated: methyl ethyl ketone and formic, acetic, oxalic, and α-methyl-α-hydroxybutyric acids, in full accord with the proposed oxidation mechanism.

Hydration of triol (I) at 96-98° does not enable the dienic ketoalcohol (II) to be isolated completely; under these conditions compound (III) undergoes partial hydrolytic cleavage to 2-methyl-2-ethyl-5-sec-butenyltetrahydro-γ-pyrone (IV) and 2-methyl-2-ethyl-5-sec-hydroxybutyltetrahydro-γ-pyrone; the latter dehydrates to (IV) under the reaction conditions. Compound (IV) is separated from the reaction products along with (III). The structure of the substituted tetrahydro-γ-pyrone (IV) is confirmed by oxidation with potassium permanganate, which leads to the same products as in the oxidation of product (III).

Special experiments showed that heating of (II) with H_2SO_4 solution to 70-80° leads to substance (III), while heating of (III) with H_2SO_4 solution to 96-98° leads to separation of product (IV).

According to our proposed reaction scheme, compound (III) is formed by removal of 1 molecule of water from a molecule of 2-methyl-2-ethyl-5-sec-hydroxytetrahydropyranylidene-2'-methyl-2'-ethyl-5'-sec-hydroxybutyltetrahydro-γ-pyrone. We believe that water is split off at the expense of the hydroxyl group at the pyranylidene ring (α). This conclusion is based on the fact that cleavage of the electronegative hydroxyl at the pyrone ring (β) is inhibited because the positive charge of the attached carbon is greatly intensified by the influence of the carbonyl oxygen which possesses a strong electron-accepting ability. Conversely, removal of hydroxyl from ring (α) is facilitated by the circumstance that the positive charge of the carbon attached to the hydroxyl will be considerably weakened by the influence of the labile π-cloud of the double bond.

Removal of this molecule of water does not proceed at the expense of the tertiary hydrogen at the carbon of the pyranylidene ring (α), as would be required by the Wagner-Zaitzev rule, for, in that case, it would be impossible to account for the formation of acetic acid on oxidation of compound (III) with potassium permanganate. Consequently, the hydrogen of the ethyl group of the secondary-hydroxybutyl radical participates in the removal of a molecule of water. This cleavage results in formation of a secondary-butenyl radical whose oxidation gives acetic acid. This water-removal mechanism is, in conflict with the Wagner-Zaitzev rule, but, as A. D. Petrov showed in a study with a group of authors [23] of the dehydration of dialkylallylcarbinols, tertiary unsaturated alcohols are always dehydrated at the expense of one of the saturated radicals. This conclusion is confirmed by the work of other authors [24].

The presence of acetic acid among the products of oxidation of (III) indicates that the primary alcoholic group participates in the cyclohydration of the dienic ketoalcohol (II) (as stated above), since, if cyclization went at the expense of the tertiary hydroxyl, the subsequent dehydration could not possibly lead to formation of a grouping capable of giving acetic acid on oxidation.

Hydrogenation of the dienic ketoalcohol (II) goes with great facility in acetic acid. One molecule of (II) takes up 4 atoms of hydrogen and forms 3,4,7-trimethyl-3-hydroxy-5-nonanone (V).

$$(II) \xrightarrow[PtO_2]{+4H} \quad \underset{\underset{CH_3\ CH_3}{|\quad\ |}}{\overset{\overset{OH}{|}}{C_2H_5-C-CH}}-CO-CH_2-\underset{\underset{CH_3}{|}}{CH}-C_2H_5$$
$$(V)$$
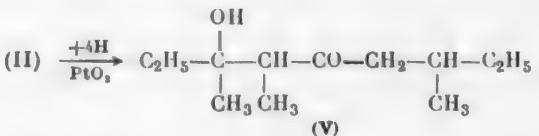
Hydrogenation of (III) also goes smoothly, and also only in acetic acid. The reaction is selective. The double bond in the side chain appears to be hydrogenated at first, to give 2-methyl-2-ethyl-5-sec-butyltetra-hydropyranylidene-2'-methyl-2'-ethyl-5-sec-hydroxybutyltetrahydro-γ-pyrone (VI); this is followed by saturation of the double bond linking the tetrahydropyranylidene ring (α) with the tetrahydro-γ-pyrone ring (β) with formation of 2-methyl-2-ethyl-5-sec-butyltetrahydropyranyl-2'-methyl-2'-ethyl-5-sec-hydroxybutyltetrahydro--γ-pyrone (VII).

$$(III) \xrightarrow[PtO_2]{2H} \cdots \xrightarrow[PtO_2]{2H}$$

(VI)

(VII)
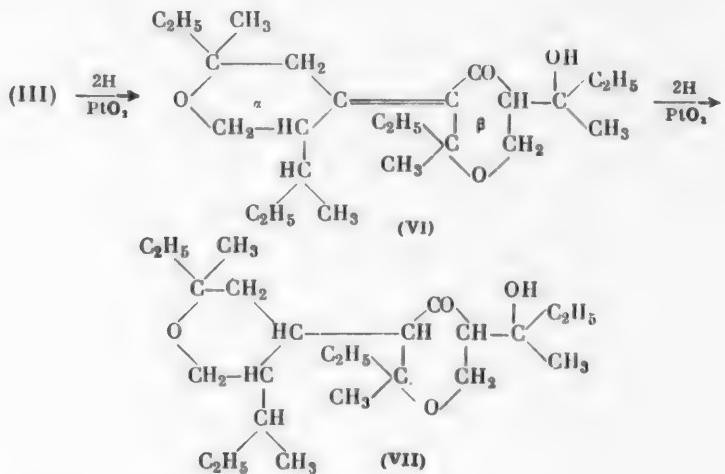
Hydrogenation of (IV) gave 2-methyl-2-ethyl-5-sec-butyltetrahydro-γ-pyrone (VIII).

$$(IV) \xrightarrow[PtO_2]{2H}$$

(VIII)
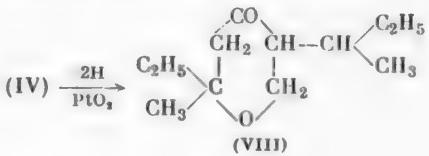
EXPERIMENTAL

3,4,7-Trimethyl-5-nonyne-3,4,7-triol (I) was prepared by condensation of methylethylacetyl carbinol with methylethylethynyl carbinol, and had the following constants: b.p. 124-126° (2 mm), $n^{20}D$ 1.4810, in agreement with the literature [25].

Hydration of 3,4,7-trimethyl-5-nonyne-3,4,7-triol (I). a) At 35-37°. A mixture of 17 ml H_2O, 2.8 ml conc. H_2SO_4, and 0.5 g $HgSO_4$ was charged into a four-necked flask equipped with mechanical stirrer, reflux condenser, thermometer, and dropping funnel. The flask was heated externally by a spiral resistance with a temperature of 60-70°. The flask was immersed in a water bath heated to 30°. 10g of (I) was introduced dropwise at such a rate that the temperature of the reaction mixture did not rise above 35-37°. After completion of the

dropwise addition, the mixture was stirred 30 min at a bath temperature of 40°. The products were extracted with ether and the ethereal extracts were worked up in the usual manner. The ether was driven off, and the products were distilled in vacuo. Two fractions were collected: 1st, b.p. 104-105° (9 mm), 4.3 g (47.3%), $n^{20}D$ 1.4849; 2nd, b.p. 120-150° (7 mm), 0.7 g.

Several distillations of the 1st fraction gave a light-green, mobile liquid, darkening slightly on keeping, and corresponding in all of its properties to 3,7-dimethyl-4-methylene-3-hydroxy-6-nonen-5-one (II).

B.p. 106-107° (11 mm), d^{20}_4 0.9574, $n^{20}D$ 1.4840, MR 58.57; calc. 58.22.

Found %: C 73.47, 73.26; H 10.07, 10.10; OH 8.15, 8.53. $C_{12}H_{20}O_2$.

Calculated %: C 73.47; H 10.21; OH 8.67.

b) At 70-80°. 21.5 g triol (I) was hydrated with a mixture of 36 ml water, 6 ml conc. H_2SO_4 and 1 g $HgSO_4$ at 70-80°. The products were worked up in the usual manner, and distilled in vacuo to give 2 fractions: 1st, b.p. 90-91° (4 mm), 6.0 g (30.6%), $n^{20}D$ 1.4840; 2nd, b.p. 182-183° (4 mm), 9.5 g (48.5%), $n^{20}D$ 1.4950.

The 1st fraction was 3,7-dimethyl-4-methylene-3-hydroxy-6-nonen-5-one (II).

From the 2nd fraction was isolated a viscous, yellow, poorly mobile liquid, corresponding to 2-methyl-2--ethyl-5-sec-butenyltetrahydropyranylidene-2'-methyl-2'-ethyl-5'-sec-hydroxybutyltetrahydro-γ-pyrone (III).

B.p. 155-156° (2 mm), d^{20}_4 1.014, $n^{20}D$ 1.4975, MR 112.2; calc. 112.5.

Found %: C 73.08, 73.42; H 10.27; 10.38; OH 4.92, 4.75. $C_{24}H_{40}O_4$.

Calculated %: C 73.42; H 10.20; OH 4.33.

c) At 96-98°. 11.0 g (I) was hydrated with a mixture of 18.7 ml water, 2.1 ml conc. H_2SO_4, and 0.7 g $HgSO_4$, with heating for 10 min on a boiling water bath (96-98°). The products were worked up as usual, and distilled in vacuo to give three fractions: 1st, b.p. 77-92° (5 mm), 0.5 g (5%), $n^{20}D$ 1.4535; 2nd, b.p. 92-120° (5 mm), 0.2 g, $n^{20}D$ 1.4640; 3rd, b.p. 186-188° (5 mm), 6.6 g (65.5%), $n^{20}D$ 1.4968.

Under the same conditions, 18.1 g of (I) was hydrated with a mixture of 30.7 ml water, 5.3 ml conc. H_2SO_4, and 1.22 g $HgSO_4$. Duration of heating, 1 hr. The products were worked up as usual, and distilled in vacuo to give three fractions: 1st, b.p. 66-67° (3 mm), 2.5 g (15.1%), $n^{20}D$ 1.4532; 2nd, b.p. 110-111° (2.5 mm), 1.8 g, $n^{20}D$ 1.4630; 3rd, b.p. 157-158° (2 mm), 9.0 g (54.3%), $n^{20}D$ 1.4978.

From the first fractions was obtained a transparent, mobile liquid which darkened on keeping and corresponded in analytical data to 2-methyl-2-ethyl-5-sec-butenyltetrahydro-γ-pyrone (IV).

B.p. 63-64° (2 mm), d^{20}_4 0.9397, $n^{20}D$ 1.4528, MR 56.35; calc. 56.60.

Found %: C 73.16, 73.00; H 10.22, 10.17; OH - none. $C_{12}H_{20}O_2$.

Calculated %: C 73.47; H 10.26.

From the third fractions ($n^{20}D$ 1.4968 and 1.4978) was isolated a viscous liquid which was 2-methyl-2-ethyl--5-sec-butenyltetrahydropyranylidene-2'-methyl-2'-ethyl-5'-sec-hydroxybutyltetrahydro-γ-pyrone (III).

Hydrogenation of 3,7-dimethyl-4-methylene-3-hydroxy-6-nonen-5-one (II). 3.2 g (II) was hydrogenated in presence of 0.03 g PtO_2 in 30 ml acetic acid at 689 mm and 28° (the catalyst was saturated with hydrogen beforehand). 985 ml was absorbed (the calculated volume for 4 H is 889.4 ml). The catalyst was filtered off, ether was added, and the acetic acid was neutralized with aqueous sodium carbonate until neutral to litmus. The ethereal solution was dried with Na_2SO_4. The ether was driven off, and the residue distilled in vacuo to give 2.0 g (61.3%) of a transparent, mobile liquid corresponding to 3,4,7-trimethyl-3-hydroxy-5-nonanone (V).

B.p. 101-102° (11 mm), d^{20}_4 0.9114, $n^{20}D$ 1.4475, MR 58.68; calc. 59.15.

Found %: C 71.99, 72.40; H 11.95, 11.89; OH 8.62, 8.41. M 210.7, 198.3. $C_{12}H_{24}O_2$.

Calculated %: C 72.00; H 12.00; OH 8.50. M 200.

Hydrogenation of 2-methyl-2-ethyl-5-sec-butenyltetrahydropyranylidene-2'-methyl-2'-ethyl-5'-sec-hydroxybutyltetrahydro-γ-pyrone (III). a) Up to addition of 1 mole of hydrogen. 4.0 g (III) was hydrogenated over 0.04 g PtO_2 in 65 ml acetic acid at 699.1 mm and 14° (the catalyst was previously saturated with hydrogen). Theoretical quantity of hydrogen 261.5 ml (2 H). After 283 ml had been taken up, hydrogenation was stopped and the product was worked up as usual and distilled in vacuo to give 3.2 g (80%) of a viscous, light-yellow liquid identical with 2-methyl-2-ethyl-5-sec-butyltetrahydropyranylidene-2'-methyl-2'-ethyl-5'-sec-hydroxybutyltetrahydro-γ-pyrone (VI).

B.p. 171-172° (2 mm), d^{20}_4 1.006, $n^{20}D$ 1.4865, MR 112.60; calc. 112.98.

Found %: C 72.90, 72.74; H 10.62, 10.49; OH 6.28, 6.08. $C_{24}H_{42}O_4$.

Calculated %: C 73.09; H 10.66; OH 4.31.

b) Up to addition of 2 moles hydrogen. 9.1 g (III) was hydrogenated over 0.06 g PtO_2 in 65 ml acetic acid at 695.4 mm and 20° (the catalyst was previously saturated with hydrogen). 1100 ml hydrogen was absorbed (4 H requires 1220 ml). The product was worked up in the usual manner and distilled in vacuo to give 8.2 g (89.7%) of viscous liquid corresponding to 2-methyl-2-ethyl-5-sec-butyltetrahydropyranylidene-2'-methyl-2'-ethyl-5'--sec-hydroxybutyltetrahydro-γ-pyrone (VII).

B.p. 190-191° (5 mm), d^{20}_4 1.006, $n^{20}D$ 1.4829, MR 112.9; calc. 113.4.

Found %: C 72.91, 72.78; H 10.98, 10.98; OH 5.59, 5.67. M 399.1, 409.5. $C_{24}H_{44}O_4$.

Calculated %: C 72.73; H 11.11; OH 4.29. M 396.

Hydrogenation of 2-methyl-2-ethyl-5-sec-butenyltetrahydro-γ-pyrone (IV). 5.1 g (IV) was hydrogenated in 40 ml acetic acid over 0.04 g PtO_2 (the catalyst was previously saturated with hydrogen). 767 ml hydrogen was taken up at 692.8 mm and 21° (calculated for 2H: 695.4 ml). The product, worked up in the usual manner, was distilled in vacuo. 4.2 g (81.5%) of a readily mobile liquid was collected; in all of its analytical data, it corresponded to 2-methyl-2-ethyl-5-sec-butyltetrahydro-γ-pyrone (VIII).

B.p. 80-82° (2 mm), d^{20}_4 0.9283, $n^{20}D$ 1.4450, MR 56.74; calc. 57.07.

Found %: C 72.95, 72.91; H 10.82, 10.89. M 204.7, 199.0. $C_{12}H_{22}O_2$.

Calculated %: C 72.80; H 11.11. M 198.

Action of a solution of H_2SO_4 (1:6) on 2-methyl-2-ethyl-5-sec-butenyltetrahydropyranylidene-2'-methyl--2'-ethyl-5'-sec-hydroxybutyltetrahydro-γ-pyrone (III). 8.5 g (III) was stirred with 36 ml H_2SO_4 (1:6) for 1 hr while being heated on a boiling water bath (96-98°). The products, worked up as in the hydration experiments, were distilled in vacuo. Three fractions were isolated: 1st, b.p. 90-91° (12 mm), 1.25 g (29.4%), $n^{20}D$ 1.4540; 2nd, b.p. 150-152° (12 mm), 0.7 g, $n^{20}D$ 1.4640; 3rd, b.p. 177-179° (4 mm), 4.2 g, $n^{20}D$ 1.4968.

From the 1st fraction was isolated a transparent, mobile liquid consisting of 2-methyl-2-ethyl-5-sec-butenyltetrahydro-γ-pyrone (IV) with b.p. 63-64° (2 mm), $n^{20}D$ 1.4528. The 3rd fraction was unchanged starting substance (III).

Action of H_2SO_4 solution (1:6) on 3,7-dimethyl-4-methylene-3-hydroxy-6-nonen-5-one (II). 3.4 g (II) was stirred with 7 ml H_2SO_4 (1:6) for 2 hr at room temperature, and then for 40 min at 70°. The products, after the usual working up, were distilled in vacuo to give three fractions: 1st, b.p. 82-110° (5 mm), 0.25 g, $n^{20}D$ 1.4687; 2nd, b.p. 110-132° (6 mm), 0.1 g, $n^{20}D$ 1.4760; 3rd, b.p. 190-191° (6 mm), 2.3 g (67.6%), $n^{20}D$ 1.4970.

Redistillation of the 3rd fraction gave a viscous liquid corresponding to the above-described 2-methyl-2--ethyl-5-sec-butenyltetrahydropyranylidene-2'-methyl-2'-ethyl-5'-sec-hydroxybutyltetrahydro-γ-pyrone (III).

B.p. 155-156° (2 mm), d^{20}_4 1.012, $n^{20}D$ 1.4961, MR 113.2; calc. 112.5.

Found %: C 73.81, 73.57; H 10.09, 10.14; OH 4.99, 4.92. M 385.5. $C_{24}H_{40}O_4$.

Calculated %: C 73.42; H 10.20; OH 4.33. M 392.

Oxidation of 3,7-dimethyl-4-methylene-3-hydroxy-6-nonen-5-one (II) with $KMnO_4$ solution. To 4.3 g (II) in 50 ml water was added dropwise a 4% solution of $KMnO_4$, which was equivalent to 6 atoms active oxygen per mole of (II). Oxidation went very easily in the course of 2-3 hr. Only 0.15 g (II) was recovered unchanged. Two fractions were separated from the neutral products in a column: b.p. 71-72° (0.4 g), and 74.78° (0.2g). The 2,4- -dinitrophenylhydrazones obtained from both of the fractions had m.p. 113-114°, and did not give a depression with authentic methyl ethyl ketone derivative. Formic acid was detected (calomel test) among the volatile acids. From the nonvolatile acids were isolated oxalic acid (1.7 g), m.p. 101-102° (mixed melting test), and α-methyl- -α-hydroxybutyric acid (1.2 g), m.p. 71-72° (mixed melting test).

Oxidation of 2-methyl-2-ethyl-5-sec-butenyltetrahydropyranylidene-2'-methyl-2'-ethyl-5'-sec-hydroxy-butyltetrahydro-γ-pyrone (III) with $KMnO_4$ solution. To 10 g (III) in 50 ml water was added a solution of 18.93 g $KMnO_4$ in 500 ml water. Oxidation went slowly. Addition of the whole of the $KMnO_4$ solution involved a period of 10-12 hr. 5 g (III) was recovered unchanged. The whole of the permanganate was therefore consumed for oxidation of 5 g (III), equivalent to 6 active oxygen atoms per mole of substance. From the neutral products was obtained 0.3 g methyl ethyl ketone. The 2,4-dinitrophenylhydrazone melted at 113-114°; a mixture with authentic methyl ethyl ketone 2,4-dinitrophenylhydrazone melted without depression.

Formic acid and acetic acid were detected (by the calomel and cacodyl oxide test, respectively) among the volatile acids. The salt of acetic acid was isolated from the silver salts.

Found %: Ag 64.04. CH_3COOAg.

Calculated %: Ag 64.67.

From the nonvolatile acids were isolated 1.0 g oxalic acid with m.p. 101-102° (mixed melting test) and 0.9 g α-methyl-α-hydroxybutyric acid with m.p. 71-72° (mixed melting test).

Oxidation of 2-methyl-2-ethyl-5-sec-butyltetrahydro-γ-pyrone (IV). To 3.6 g (V) in 50 ml water was added dropwise in the course of 5-6 hr a solution of 9.66 g $KMnO_4$ in 250 ml water, corresponding to 5 active atoms of oxygen per mole of substance. From the neutral products of oxidation was isolated 0.4 g methyl ethyl ketone, which gave a 2,4-dinitrophenylhydrazone with m.p. 113-114° (mixed melting test). Formic acid and acetic acid were detected (by the calomel and cacodyl oxide test, respectively) in the volatile acids (1.06 g). The silver salt of acetic acid was obtained. From the nonvolatile acids were isolated 0.7 g oxalic acid with m.p. 101-102° (mixed melting test) and 0.5 g α-methyl-α-hydroxybutyric acid with m.p. 71-72° (mixed melting test).

Oxidation of (IV) consequently yielded methyl ethyl ketone among the neutral products and formic, oxalic, and α-methyl-α-hydroxybutyric acids among the acids.

SUMMARY

1. The hydration of 3,4,7-trimethyl-5-nonyne-3,4,7-triol was studied.

2. It was shown that at 30-40° under hydration conditions, 3,4,7-trimethyl-5-nonyne-3,4,7-triol is transformed into a dienic ketoalcohol (3,7-dimethyl-4-methylene-3-hydroxy-6-nonen-5-one), which, at 70-80°, undergoes further conversion to 2-methyl-2-ethyl-5-sec-butenyltetrahydropyranylidene-2'-methyl-2'-ethyl-5'- -sec-hydroxybutyltetrahydro-γ-pyrone.

3. With dilute sulfuric acid at 96-98° the molecule of 2-methyl-2-ethyl-5-sec-butenyltetrahydropyranylid-ene-2'-methyl-2'-ethyl-5'-sec-hydroxybutyltetrahydro-γ-pyrone underwent hydrolytic cleavage into 2 molecules of the substituted tetrahydro-γ-pyrone.

4. A mechanism of all the transformations of 3,4,7-trimethyl-5-nonyne-3,4,7-triol under the conditions of the hydration reaction is advanced.

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TERTIARY TRIHYDRIC ALCOHOLS OF THE ACETYLENIC SERIES
AND THEIR TRANSFORMATIONS
XIII. THE HYDRATION OF 2,3,6-TRIMETHYL-4-HEPTYNE-2,3,6-TRIOL

V. I. Nikitina, A. B. Zegel'man and A. Kh. Khamatov

Institute of Chemistry, Academy of Sciences, Tadzhik SSR

Original article submitted May 23, 1957

In the preceding communication [1], we described the hydration of 3,4,7-trimethyl-5-nonyne-3,4,7-triol under the conditions of the Kucherov reaction. This reaction went with formation of 2-methyl-2-ethyl-5-sec-butenyltetrahydropyranylidene-2'-methyl-2'-ethyl-5'-sec-hydroxybutyltetrahydro-γ-pyrone.

In the present communication, we present the results obtained in the hydration of 2,3,6-trimethyl-4-heptyne--2,3,6-triol (I), the simplest representative of this series of triols.

Hydration of (I) was conducted at about 40°, and only one product was isolated — 2,2-dimethyl-5-hydroxy-isopropyltetrahydropyranylidene-2,2'-dimethyl-5'-hydroxyisopropyltetrahydro-γ-pyrone (II). No intermediate products could be isolated, in contrast to what occurred in the hydration of 3,4,7-trimethyl-5-nonyne-3,4,7-triol [1].

We do not think there is any reason why the mechanism of transformation of 2,3,6-trimethyl-4-heptyne--2,3,6-triol should differ from that for the above-mentioned nonynetriol. On the contrary, the formation in the present case of (II) — a compound containing two hydroxyl groups — only confirms the previously advanced mechanism since, in the proposed scheme, the substance analogous to (II) was only a hypothetical intermediate product which changed into the product of its partial dehydration.

In the present case, however, only the action of dilute sulfuric acid on compound (II) at about 100° leads to detachment of one molecule of water; this process takes place at the hydroxyisopropyl group located, as established in the preceding communication [1], at the tetrahydropyranylidene ring. It results in formation of 2,2--dimethyl-5-isopropenyltetrahydropyranylidene-2',2'-dimethyl-5'-hydroxyisopropyltetrahydro-γ-pyrone (III). Under these conditions, the latter undergoes partial hydrolytic cleavage to 2,2-dimethyl-5-isopropenyltetrahydro--γ-pyrone (IV) and (apparently) to 2,2-dimethyl-5-hydroxyisopropyltetrahydro-γ-pyrone, which immediately dehydrates to (IV).

The composition of (III) and (IV) is confirmed by all of the known analytical data. Their structure is also confirmed by their oxidation with potassium permanganate. Oxidation of each gives identical products: acetone and formic, acetic, oxalic, and α-hydroxyisobutyric acids.

Hydrogenation of (II) over platinum oxide does not take place in methanol solution, but it proceeds fairly smoothly in acetic acid solution. 2 moles of hydrogen are taken up, the first of which exclusively substitutes one of the hydroxyl groups. Exactly as in the dehydration, we assume that hydrogenation is directed at the hydroxyl group at the hydroxyisopropyl radical in the tetrahydropyranylidene ring. This leads to formation of 2,2-dimethyl--5-isopropyltetrahydropyranylidene-2',2'-dimethyl-5'-hydroxyisopropyltetrahydro-γ-pyrone (V). The second molecule of hydrogen hydrogenates the double bond between the two rings to form the fully saturated compound — 2,2-dimethyl-5-isopropyltetrahydropyranyl-2'2'-dimethyl-5'-hydroxyisopropyltetrahydro-γ-pyrone (VI).

A 2,4-dinitrophenylhydrazone could only be obtained for (II). Attempts to prepare derivatives of ketones for all of the remaining compounds were unsuccessful.
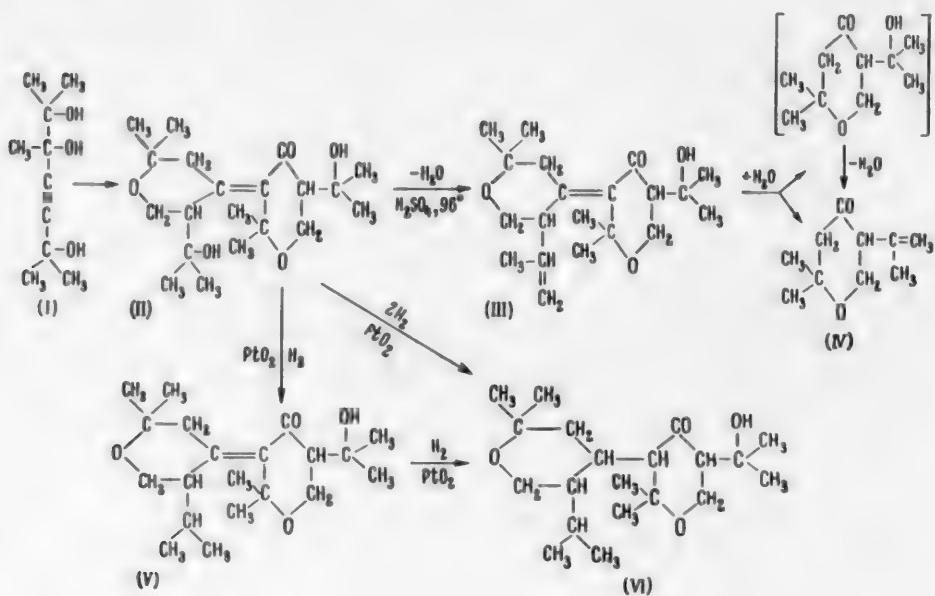
EXPERIMENTAL

Hydration of 2,3,5-trimethyl-4-heptyne-2,3,6-triol (I). The triol was prepared by condensation of dimethyl-acetylcarbinol with dimethylethynylcarbinol and had b.p. 122° (2.5 mm) and m.p. 81-82° (from benzene). These data are in agreement with the literature [2].

18.5 g trimethylheptynetriol (I) was added in small portions to a mixture of 36 ml water, 6 ml conc. H_2SO_4 and 1.35 g $HgSO_4$ with vigorous shaking. Heat was evolved and the temperature was kept at not higher than 40° by cooling the reaction flask with cold water. The reaction mixture became dark red. The product was extracted with ether. The ethereal extracts were washed with sodium carbonate solution and water until neutral to litmus, and dried with calcined Na_2SO_4. The ether was driven off, and the residue recrystallized from ligroine. Several recrystallizations gave 10.50 g (59.8%) of stout, regular, transparent crystals with m.p. 127-128°, consisting of 2,2-dimethyl-5-hydroxyisopropyltetrahydropyranylidene-2',2'-dimethyl-5'-hydroxyisopropyltetrahydro-γ-pyrone (II). No other products were isolated.

Found %: C 67.70, 67.79; H 9.79, 9.77; OH 10.12, 10.07. M 365.3, 354.0. $C_{20}H_{34}O_5$.

Calculated %: C 67.74; H 9.67; OH 9.60. M 354.

2,4-Dinitrophenylhydrazone: m.p. 165-166°.

Found %: N 10.51, 10.59. $C_{26}H_{38}O_8N_4$.

Calculated %: N 10.49.

Dehydration of 2,2-dimethyl-5-hydroxyisopropyltetrahydropyranylidene-2',2'-dimethyl-5'-hydroxyisopropyl-tetrahydro-γ-pyrone (II). 5 g pyrone (II) was stirred in a three-necked flask, fitted with mechanical stirrer, reflux condenser, and thermometer, with 28 ml H_2SO_4 solution (1:6) for 2 hr while heating on a boiling water bath (bath temperature 96°).

The products were worked up in the usual manner and distilled in vacuo. The following fractions were collected: 1st, 71-72° (14 mm), 0.9 g (19%), $n^{20}D$ 1.4433; 2nd, 130-133° (14 mm), 0.2 g, $n^{20}D$ 1.4620; 3rd, 161 to 163° (7 mm), 1.9 g (40%), $n^{20}D$ 1.4900.

The 71-72° (14 mm) fraction was a transparent, readily mobile liquid with a camphor-like odor. Judging by all of the data, it is 2,2-dimethyl-5-isopropenyltetrahydro-γ-pyrone (IV).

B.p. 78-79° (20 mm), d^{20}_4 0.9330, $n^{20}D$ 1.4420, MR 47.64; $C_{10}H_{16}O_2F$. Calc. 47.37.

Found %: C 71.97, 71.12; H 9.49, 9.35. $C_{10}H_{16}O_2$.

Calculated %: C 71.44; H 9.52.

The 161-163° (7 mm) fraction was a transparent, poorly mobile, viscous liquid — 2,2-dimethyl-5-isopropenyl-tetrahydropyranylidene-2'2'-dimethyl-5'-hydroxyisopropyltetrahydro-γ-pyrone (III).

B.p. 137-138° (2 mm), d^{20}_4 1.038 , $n^{20}D$ 1.4910, MR 93.76; $C_{20}H_{32}O_4F_2$. Calc. 94.01.

Found %: C 71.68, 71.64; H 9.55, 9.50; OH 4.79, 5.12. $C_{20}H_{32}O_4$.

Calculated %: C 71.43; H 9.52; OH 5.06.

Oxidation of 2,2-dimethyl-5-isopropenyltetrahydropyranylidene-2',2'-dimethyl-5'-hydroxyisopropyltetra-hydro-γ-pyrone (III) with $KMnO_4$ solution. A solution of 13.1 g $KMnO_4$ in 320 ml water was added dropwise to 4.0 g (III) in 50 ml water (the amount of oxidizing agent was equivalent to 9 active oxygen atoms per mole of substance). Addition of the whole of the $KMnO_4$ solution had to be spread over 8-10 hr due to the slowness of oxidation. 0.2 g liquid was isolated from the neutral products of oxidation, and gave a 2,4-dinitrophenylhydra-zone with m.p. 122-123°. No depression in admixture with authentic acetone 2,4-dinitrophenylhydrazone.

Steam distillation of the acidic oxidation products gave acids whose neutralization consumed 151 ml 0.109 N NaOH solution, equivalent to 0.655 g NaOH. Qualitative tests established the presence of formic acid (calomel test) and acetic acid (formation of cacodyl oxide and analysis of the silver salt).

Found %: Ag 64.42. CH_3COOAg.

Calculated %: Ag 64.67.

From the nonvolatile acids were isolated 1.6 g oxalic acid with m.p. 101-102° (mixed melting test) and 1.3 g α-hydroxyisobutyric acid with m.p. 78-79° (mixed melting test).

Oxidation of 2,2-dimethyl-5-isopropenyltetrahydro-γ-pyrone (IV) with $KMnO_4$ solution. To 3.0 g (IV) in 50 ml water was added dropwise a solution of 9.9 g $KMnO_4$ in 300 ml water. Oxidation extended over 4-5 hr. From the neutral products was isolated 0.3 g acetone, which gave a 2,4-dinitrophenylhydrazone with m.p. 124-125° (mixed melting test). The volatile acids (0.95 g) were found to include formic acid (calomel test) and acetic acid (cacodyl oxide test). The silver salt of acetic acid was prepared. From the nonvolatile acids were isolated 0.6 g oxalic acid with m.p. 101-102° (mixed melting test) and 0.6 g α-hydroxyisobutyric acid with m.p. 78-79° (mixed melting test).

Hydrogenation of 2,2-dimethyl-5-hydroxyisopropyltetrahydropyranylidene-2'2'-dimethyl-5-hydroxyiso-propyltetrahydro-γ-pyrone (II) up to addition of 1 mole of hydrogen. 0.03 g PtO_2 in 30 ml acetic acid was satur-ated with hydrogen. Saturation required 140 ml. Addition was then made of 5.2 g (II) in 40 ml acetic acid. The required volume of hydrogen (2 H) is 383.8 ml at 694.2 mm and 18°. Hydrogenation was stopped after absorption of 420 ml. The catalyst was filtered off. The acetic acid was distilled off in the vacuum of a water jet pump, and the residue was dissolved in ether. The ethereal solution was washed with sodium carbonate solution and water until neutral and dried with Na_2SO_4. The ether was driven off, and the residue was distilled in vacuo to give 4 g (80.6%) of a yellowish, viscous liquid — 2,2-dimethyl-5-isopropyltetrahydropyranylidene-2',2'-dimethyl--5'-hydroxyisopropyltetrahydro-γ-pyrone (V).

B.p. 141-142° (2 mm), $n^{20}D$ 1.4810, d^{20}_4 1.021, MR 94.21; $C_{20}H_{34}O_4F$. Calc. 94.51.

Found %: C 70.66, 70.84; H 10.21, 10.20; OH 5.50, 5.39. $C_{20}H_{34}O_4$.

Calculated %: C 71.01; H 10.06; OH 5.03.

Hydrogenation of 2,2-dimethyl-5-isopropyltetrahydropyranylidene-2',2'-dimethyl-5'-hydroxyisopropyltetra-hydro-γ-pyrone (V). 0.03 g PtO_2 in 20 ml acetic acid was saturated with hydrogen (130 ml required for satura-tion). Addition was then made of 4 g of the product with b.p. 141-142° (2 mm) in 30 ml acetic acid. The re-quired volume of hydrogen (2 H) was 306.7 ml (685.4 mm, 25°). The amount absorbed was 307 ml. The catalyst was filtered off, the acetic acid was taken off in the vacuum of a water jet pump, the residue was dissolved in ether, and the ethereal solution was washed with sodium carbonate solution and water until neutral. The ether was driven off and the residue [3.5 g (87%) of viscous, transparent liquid] was twice distilled in vacuo.

B.p. 129-131° (1 mm), $n^{20}D$ 1.4752, d^{20}_4 1.014, MR 94.50; calc. 94.98.

Found %: C 70.52, 70.50; H 10.74, 10.75; OH 5.4, 5.2. M 323, 325.6. $C_{20}H_{36}O_4$.

Calculated %: C 70.58; H 10.59; OH 5.0. M 340.

The compound is 2,2-dimethyl-5-isopropyltetrahydropyranyl-2',2'-dimethyl-5'-hydroxyisopropyltetrahydro-
-γ-pyrone (VI).

Hydrogenation of 2,2-dimethyl-5-hydroxyisopropyltetrahydropyranylidene-2',2'-dimethyl-5'-hydroxyiso-
propyltetrahydro-γ-pyrone (II) up to addition of 2 moles hydrogen. 4 g pyrone (II) was hydrogenated over 0.03 g
PtO_2 in 70 ml acetic acid (after the catalyst had been saturated with hydrogen). 600 ml hydrogen was taken up
at 695.3 mm and 15.5°. The required volume of hydrogen (4 H) is 584.8 ml. The product was worked up as in
the preceding experiments, and distilled in vacuo to give 3.3 g (93.7%) viscous liquid with b.p. 129-130° (1 mm),
$n^{20}D$ 1.4752. It was 2,2-dimethyl-5-isopropyltetrahydropyranyl-2',2'-dimethyl-5'-hydroxyisopropyltetrahydro-
-γ-pyrone (VI).

SUMMARY

1. 2,3,6-Trimethyl-4-heptyne-2,3,6-triol was hydrated by the Kucherov method.

2. It was shown that, under the conditions of the Kucherov reaction, the trimethylheptynetriol is converted
into 2,2-dimethyl-5-hydroxyisopropyltetrahydropyranylidene-2',2'-dimethyl-5'-hydroxyisopropyltetrahydro-γ-
-pyrone, which confirms our previously suggested mechanism of the transformations of 3,4,7-trimethyl-5-nonyne-
-3,4,7-triol.

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THE CONDENSATION OF ALDEHYDES WITH KETONES

III. THE DIKETONIC CONDENSATION OF CYCLOHEXANONE WITH BENZALDEHYDE

(A NEW TYPE OF CONDENSATION OF ALICYCLIC KETONES WITH AROMATIC ALDEHYDES)

M. N. Tilichenko and V. G. Kharchenko

Saratov State University

Original article submitted June 1, 1958

We have established [1] that in alcoholic alkaline media monoarylidenecyclanones are very easily dimerized, while diarylidenecyclanones not less easily add on one molecule of cyclohexanone. Each of the reactions constitutes a Michael condensation:
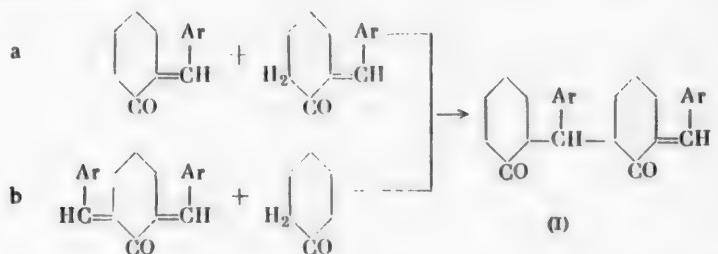
In the light of these facts, we were surprised that numerous papers [2-6] on the condensation of cyclanones with aromatic aldehydes mention only the products of aldol – crotonic condensation and never refer to the formation of 1,5-diketones of the type of (I). We believe the reason to be that the aldol-crotonic condensation of alicyclic ketones of the type of cyclohexanone with benzaldehyde and similar aldehydes, which is usually carried out in aqueous alcoholic media, goes with exceptional facility, and the resulting products are poorly soluble in the media in question and are immediately removed from the sphere of reaction. For purely fortuitous reasons, the products of the aldol-crotonic condensation were therefore assumed to be the end products of the reaction.

With these considerations in mind, we condensed cyclohexanone with benzaldehyde under conditions such that mono- and dibenzylidenecyclohexanones remained in solution after their formation. After standing at room temperature for two or three days (depending on the alkali concentration), the reaction solutions deposited a voluminous mass of white crystals of benzylidenebenzylidenedicyclohexanone (I) (Ar = C_6H_5). Consequently, our hypothesis was confirmed. We thus demonstrated for the first time the applicability of the diketonic condensation [7] also to the field of condensation of alicyclic ketones with aromatic aldehydes.

In addition to diketone (I) we detected in the reaction products a small quantity (about 4%) of phenyltricyclohexanolone [2-phenyl-3,4-tetramethylenebicyclo-(3,3,1)-9-nonanone-4-ol] (II), which is easily formed, according to our earlier results [8], from monobenzylidenecyclohexanone and cyclohexanone.
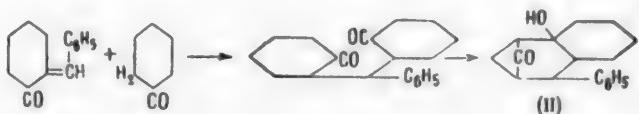
The reaction mixture can therefore only contain a little monobenzylidenecyclohexanone, and the formation of the 1,5-diketone (I) probably proceeds mainly via the Michael condensation of cyclohexanone with the intermediately formed dibenzylidenecyclohexanone.

EXPERIMENTAL

Condensation of Cyclohexanone with Benzaldehyde

Experiment 1. A solution of 6 g cyclohexanone and 2 g benzaldehyde in 30 ml 0.3 N alcoholic NaOH was allowed to stand motionless at room temperature. After 3 days, a voluminous precipitate of white crystals of benzylidenebenzylidenedicyclohexanone (I) was formed. The crystals were filtered and washed with alcohol and then with water. Yield 1.8 g (51%), m.p. 135-136° (from a 1:2 mixture of benzene and ligroine). A mixture with a standard specimen of benzylidenebenzylidenedicyclohexanone, recrystallized from the same solvent as was used for the preparation, melted without depression.

After neutralization with dilute hydrochloric acid, the filtrate deposited a soft precipitate which solidified to a pale-yellow amorphous powder after standing under water. Yield 1.3 g. The powder did not crystallize. From the hot acetone solution separated 0.17 g crystals with m.p. 207-209°, corresponding to phenyltricyclohexanolone (II) [8] and identified by a mixed melting test with an authentic specimen.

Experiment 2. This experiment differed from the first only in that 30 ml of 1 N NaOH was taken instead of 0.3 N alcoholic NaOH. In this case, the precipitate of benzylidenebenzylidenedicyclohexanone came down on the second day. Yield 1.7 g. As in the first case, the filtrate deposited a noncrystallizing product, from which was obtained 0.15 g (4.3%) of phenyltricyclohexanolone (II).

Condensation of Cyclohexanone with Dibenzylidenecyclohexanone

A mixture of 2.5 g* dibenzylidenecyclohexanone, 5 g cyclohexanone, and 30 ml 0.3 N alcoholic sodium hydroxide was left at room temperature. After 2 days a little dibenzylidenecyclohexanone was still undissolved. Another 10 ml of the alkali solution was added to dissolve it. On the third day, the solution set to a crystal slurry. The crystals were collected as described in Experiment 1, and 1.7 g dry crystals was obtained. After neutralization and dilution with water, the filtrate deposited a soft precipitate which solidified after standing under water. Recrystallization from alcohol gave a further 0.7 g crystals. Total yield of crystals 2.4 g (70%). Judging by the melting point and the mixed melting test, the crystals consisted of benzylidenebenzylidenedicyclohexanone (I).

Consequently, the general picture of the formation of diketone (I) in the first experiments is fully identical with that in the present case, except that here the yield is higher and, as is perfectly natural, the formation of phenyltricyclohexanolone is not observed.

SUMMARY

Diketonic condensation of cyclohexanone with benzaldehyde is effected. It is shown that in an alcoholic alkaline medium cyclohexanone and benzaldehyde give, instead of the usual dibenzylidenecyclohexanone, a 1,5-diketone (benzylidenebenzylidenedicyclohexanone). A reaction mechanism is advanced.

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* In Experiment 1, 2.58 g dibenzylidenecyclohexanone should be theoretically formed as an intermediate.

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* Original Russian pagination. See C.B. translation.

* * In Russian.

CONDENSATION OF ALDEHYDES WITH KETONES

IV. THE FURFUROLYSIS EFFECT IN THE ALKALINE CONDENSATION OF KETOLS

AND A 1,5-DIKETONE WITH FURFURAL

M. N. Tilichenko and V. G. Kharchenko

Saratov State University

Original article submitted June 2, 1958

We observed the following extremely interesting effect on attempting to condense with furfural our previously prepared [1] phenyl-(I) and furyl-(II) tricyclohexanolones [2-phenyl- and furyl-3,4-tetramethylene-bicyclo-(3,3,1)-nonan-9-one-4-ol], and also furfurylidene-fural-dicyclohexanone (III) [2]: under the action of furfural, compounds (I), (II), and (III) are fairly easily converted into difuralcyclohexanone (IV) (Scheme 1).

This cleavage reaction can be regarded as a furfurolysis since, in the absence of furfural,compounds (I), (II), and (III) under the same conditions remain substantially unchanged. It is interesting that a similar effect does not take place under the influence of benzaldehyde:

Scheme 1
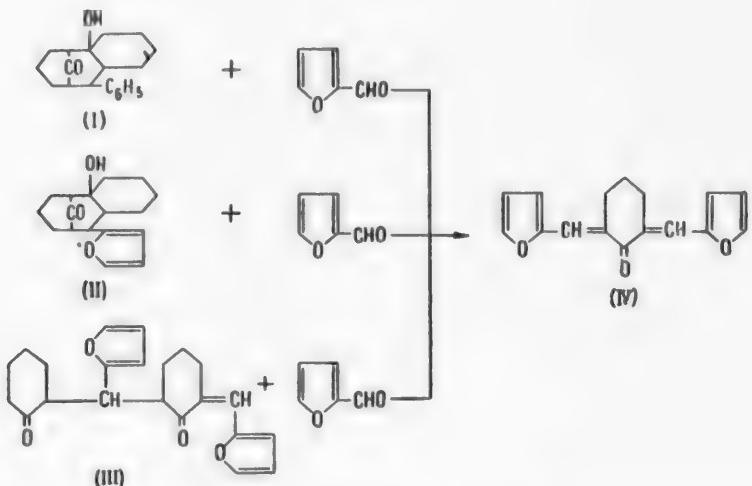
The process can be represented as a combination of the following two main reactions: hydrolysis and lydenic condensation of the products of hydrolysis with furfural. The proposed mechanism is illustrated by Scheme 2 (a,b).

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*Furfural displaces benzaldehyde from benzylidenecyclohexanone, and this process can also be regarded as the association of hydrolysis with lydenic condensation [3].

Scheme 2

a (1) ... OH | CO | Ar ... Hydrolysis / Aldol condensation ... Hydrolysis / Michael condensation ... CH | CO | Ar + CO

(2) ... + 2 ... CHO

(3) Ar=... ... CH + ... CHO → CH= | | =CH

(4) x ... Ar=C_6H_5 ... CH | C_6H_5 + 2 ... CHO

b ... CH ... CH ... 1 / 2 ... → + ... CH ... CH ... → 2 ... =CH
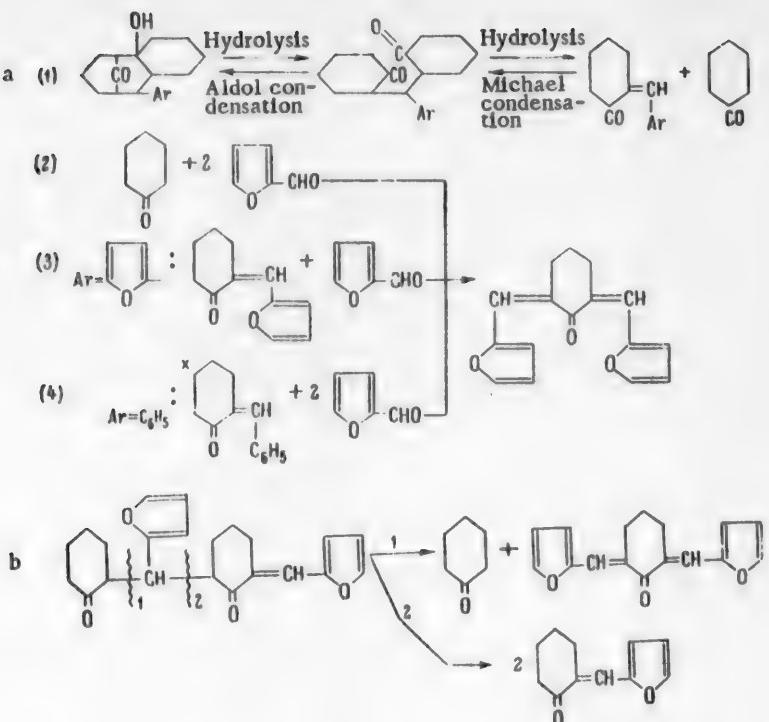
The cyclohexanone and furalcyclohexanone formed in Reaction (b) further condense with furfural to form difuralcyclohexanone.

Alkaline cleavage of cyclic β-ketones (cyclohexanolones) to 1,5-diketones was observed by Dieckmann and Fischer [4] and by one of us and Bérbulesku [5]. This reaction is the reverse of the intramolecular aldol condensation. In principle, the latter is just as reversible as the intermolecular aldol condensation. Alkaline cleavage of 1,5-diketones is the reverse of the Michael reaction. This cleavage has been described in the literature [6,7,4].

Scheme 2 (a,b) explains the furfurolysis that we observed as a process of linking by furfural of the products of hydrolysis (I, II, III) to form the stable difuralcyclohexanone (IV) which is difficultly soluble in an alcoholic medium, due to which the equilibrium in the system is shifted in the direction of (IV).

What still remains obscure, however, is why a similar cleavage does not take place in presence of benzaldehyde. Benzaldehyde could also be expected to give with the products of hydrolysis (at any rate, the phenyl-ketol), a not less stable dibenzalcyclohexanone fairly difficultly soluble in alcohol and, therefore, resulting in an equilibrium shift toward formation of the latter. Probably furfural here not only functions as a bridge between the products of hydrolysis, but also intervenes directly in the cleavage of the ketols and 1,5-diketones. The mechanism of this direct action is still obscure.

EXPERIMENTAL

Action of furfural on furyltricyclohexanolone (II). 1.37 g ketol (m.p. 185-186.5°) was mixed with 1.5 g furfural and 20 ml 1 N alcoholic NaOH. After 3 hr at room temperature, and nearly instantaneously with heating on a water bath, orange crystals of difuralcyclohexanone (IV) were formed, m.p. 144-145° (from alcohol). A mixture with authentic difuralcyclohexanone melted without depression. Yield of crystals 1.1 g.

Action of furfural on phenyltricyclohexanolone (I). This reaction proceeds satisfactorily when a large excess of furfural is used and the mixture is heated. 1.42 g ketol (m.p. 207-209°) is mixed with 7 g furfural and 50 ml of 1 N alcoholic NaOH. The solution is boiled 15 min and stood at room temperature. After a short time,

orange crystals of difuralcyclohexanone (IV) start to separate; these are filtered off after 36 hr, washed with alcohol, and then with water, and dried in the air. Yield 0.65 g; m.p. 143-145° (from alcohol). No depression in admixture with authentic difuralcyclohexanone.

Found %: C 75.86; H 5.82. $C_{16}H_{14}O_3$.

Calculated %: C 75.59; H 5.51.

Action of furfural on furfurylidenefuraldicyclohexanone. The reaction in the direction of formation of difuralcyclohexanone is effected with the same facility as the corresponding reaction of the furylketol (II). From a solution of 1 g diketone and 1 g furfural in 20 ml 1 N alcoholic NaOH was obtained, after 3-4 hr, 0.5 g of crystals of difuralcyclohexanone (IV). M.p. 143-145° (from alcohol). A mixture with authentic substance melted without depression.

Behavior of compounds (I), (II), and (III) toward benzaldehyde. Experiments were conducted as above, but using benzaldehyde in place of furfural. In all of the cases, the starting compounds (I), (II), and (III) were recovered unchanged.

SUMMARY

1. It was established that in an alcoholic alkaline medium in presence of furfural, phenyl- and furyltricyclohexanolones, as well as furfurylidenefuraldicyclohexanone, are easily cleaved with formation of difuralcyclohexanone. This process goes with greater facility with furyltricyclohexanolone and furfurylidenefuraldicyclohexanone than with phenyltricyclohexanolone.

2. Phenyltricyclohexanolone, furyltricyclohexanolone, and furfurylidenefuraldicyclohexanone remain unchanged in presence of benzaldehyde.

3. Ideas about the mechanism of the observed process of furfurolysis are discussed.

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COPREPARATION OF ALCOHOLS AND KETONES FROM
OXO SYNTHESIS ALDEHYDES AND SECONDARY ALCOHOLS

D. M. Rudkovskii, M. M. Ketslakh and É. S. Zonis

Scientific Research Institute for Processing of Petroleum and
Production of Synthetic Liquid Fuel, Leningrad

Original article submitted May 12, 1958

We know that the oxo synthesis can yield a number of aldehydes which are starting substances for the synthesis of primary alcohols [1,2].

In the present work, we investigated the coproduction of C_6 to C_8 alcohols and lower ketones (acetone and methyl ethyl ketone) from oxo synthesis aldehydes and secondary alcohols on the basis of the Meerwein-Ponndorf reaction discovered in 1925 [3]. Nearly all of the publications dealing with this reaction recommend reduction with the help of aluminum isopropoxide in a medium of isopropyl alcohol. The isopropoxide is a strong reducing agent [4]. Aluminum ethoxide is used very much more rarely; while being a weaker reducing agent, it is a very much stronger catalyst of the condensation reaction [5]. Reduction with aluminum sec-butoxide has been rarely applied. Reference has been made only to its use in the reduction of ketones and aromatic aldehydes [6,7].

It is noteworthy that the Meerwein-Ponndorf reaction gave the best results for ketones [8,9]. In the reduction of aliphatic aldehydes susceptible to condensation reactions (ether and aldol condensations), the reaction goes very largely in the direction of formation of condensation products,
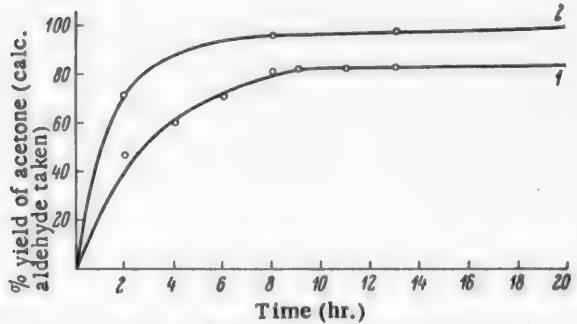
Acetone yield as a function of reaction period. Explanation in text.

and the yields of alcohols are low [10]. The sole exception is citral, which is reduced to the extent of 70% [11]. An excess of alkoxide over the equivalent amount is recommended for minimizing the quantity of condensation products [12]. But the large quantities of alkoxides, and the relatively low yields of alcohols make the process very uneconomic. Ketones are also formed in the reduction of aldehydes to alcohols with the help of aluminum sec-alkoxides. These ketones distil over with the solvent during the reaction. Means for isolation of the pure ketones are not mentioned in the literature.

In the present work, we developed a method of preparation of aliphatic C_6 to C_8 alcohols and ketones (acetone and methyl ethyl ketone) in high yields and with low consumption of aluminum alkoxides by using cobalt carbonyls as activators. Starting point for the reduction was an oxo synthesis hydrocarbon solution containing 28 to 36% C_6 to C_8 aldehydes. Reduction was performed in presence of aluminum isopropoxide or sec-butoxide in a solution of the corresponding alcohol.

In the investigation, the influence of the following factors on the yield of end products was studied: the activator (cobalt carbonyls), quantity of catalyst, the polarity of the solvent, the manner of addition of the aldehydes to the aluminum isopropoxide solution (Tables 1 to 3). The velocity of reduction was also studied (see figure).

TABLE 1

Influence of Addition of Cobalt Carbonyls and of the Polarity of the Solvent on the Process of Reduction of C_6-C_8 Aldehydes. Mean Equivalent Aluminum Isopropoxide/ Aldehydes Ratio 0.5:1

Expt. No.	Composition of starting material (in %)				Solvent for aldehydes	% concentration in reac. mix. of		Aldehydes reacted (in %)	% yield on basis of reacted aldehydes	
	alde-hydes	acids	esters	alco-hols		alde-hyde	cobalt carbonyls		of ace-tone	of C_6-C_8 alcohols***
1	90	—	—	—	Isopropyl alcohol	22	—	98	76	70
2	91.5	—	—	—	The same	15.3	—	100	75	—
3	95	—	—	—	" "	10.2	—	99	73	77
4*	95	—	—	—	" "	10.2	0.006	97	80	87
5	89	—	—	—	Isopropyl alcohol +	10.2	0.004	97	88	85
6	89	—	—	—	heptane	10.2	0.003	97	84	83
7	38	2	8	6	Isopropyl alcohol +	12.8	0.003	99	96	93
8	27.9	0.8	7	4	C_6-C_7 hydrocarbons	10.4	~0.002	97	97	96
9	30.3	—	11	1.1	from oxo synthesis	10.7	0.001	98	95	90
10	28	—	11	1.1	catalyzate	10.1	0.001	99	94	92
11**	27.9	0.8	7	4		10.7	~0.002	97	85	76

*In Expts. 4-6, a hydrocarbon solution of cobalt carbonyls was added to the reaction mixture of pure aldehydes, while, in Expts. 7-10, oxo synthesis aldehydes containing cobalt carbonyls remaining after the reaction were used.
**Experiment performed without continuous distillation of acetone during the reaction.
***Yield calculated with allowance for the 4% alcohol dissolved in the aqueous distillate resulting from distillation with steam.

TABLE 2

Influence of Amount of Aluminum Isopropoxide on the Yield of C_6-C_8 Alcohols

Expt. No.	Composition of starting material (in %)				Conc. of aldehydes in solution	Experimental conditions*		Aldehydes reacted (%initial quantity)	Yield on basis of aldehydes consumed (%)		Alum. iso.** (calc. as alum.) con-sumed in prod. of alcohols, ketones
	alde-hydes	acids	esters	alco-hols		mean equiv. ratio of alum. iso. to aldehydes in whole expt.	equiv. ratio of alum. iso. to aldehydes, dur-ing period of add. of alde-hydes to reac. mixture		acet-one	C_6-C_8 alco-hols	
1	36.5	2.0	6	8	13.7	0.25:1	Whole of alde-hyde added to reaction mix-ture, start of experiment	—	—	81	—
2	36.3	2.0	6	7.5	14.7	0.50:1		98	84	80	3.0
3	27.9	0.8	7	4	10.2	0.50:1		98	—	83	3.2
4	28.0	—	11	1	10.1	0.55:1	33:1	99	94	92	3.0
5	30.3	0.8	7	4	10.8	0.50:1	174:1	98	95	92	2.8
6	27.9	0.8	7	4	10.4	0.55:1	792:1	97	97	96	2.9
7	37.0	1.5	6	8	12.5	0.25:1	360:1	93	92	91	1.4
8	27.6	—	11	1	11.0	0.15:1	102:1	90	83	77	1.0
9	38.0	2.0	9	6	11.0	0.12:1	—	—	84	—	—

*In Expts. 1-3 the aldehyde was added quickly; in Expts. 4-9 it was added at a uniform rate.
**Alum. iso. - Aluminum isopropoxide.

TABLE 3

Reduction of C_6–C_8 Aldehydes with Aluminum sec-Butoxide in a Medium of sec-Butyl Alcohol (mean equivalent ratio of aluminum butoxide to aldehydes 0.5:1)

Composition of starting material (%)				Concentration of aldehydes in reaction mixture	Aldehydes reacted (%)	Yield on reacted aldehydes (%)	
aldehydes	acids	esters	alcohols			of methyl ethyl ketone	of C_6–C_8 alcohols
30	–	11	1	15	97	91	86
30	–	11	1	15	97	95	91

The influence of an activator was studied by taking aldehydes in some experiments free of cobalt carbonyls, and, in other experiments, with a content of some thousandths of a percent of activator (calculated as cobalt). In the first case, the average yield of alcohol was 73% and that of acetone 74% (Table 1, Expts. 1-3). In the second case, using 0.003 to 0.006% cobalt (reckoned on the aldehyde), the average yield of alcohols and acetone rose to 85% (Table 1, Expts. 4-6).

The yield of alcohols and acetone increases still further (to 95%) if the aldehydes are used in the form of the mixture as obtained in the oxo synthesis (Table 1, Expts. 7-10), and which contains cobalt carbonyls formed in the process of carbonylation (oxo synthesis catalyzate) [1]. The results of these experiments indicate that the high activity (in comparison with artificial mixtures) of the cobalt carbonyls remaining in the oxo aldehydes is due to their existence in a more active form. From this aspect, this process of coproduction of alcohols and ketones acquires great practical importance for oxo synthesis aldehydes containing traces of cobalt carbonyls.

The experiments showed that the polarity of the solvent used during reduction does not influence the yield of alcohols (Table 1, Expts. 5, 6, and 4). Continuous distillation of acetone during the reaction leads to increased yield of alcohols (Table 1, Expt. 11 and Expts. 7-10).

With the aim of establishing the effect of the quantity of isopropoxide on the reduction process, a set of experiments was run with equivalent ratios of aldehyde to aluminum isopropoxide of 1:0.25 and 1:0.5. The results of Expts. 2 and 3 (Table 2) show that the maximum yield of alcohols when using 0.5 equiv. of catalyst is 83%; about 15% of the original aldehydes undergoes secondary transformations. Subsequent halving of the quantity of aluminum isopropoxide scarcely affects the yield (Table 2, Expt. 1). The condensation reaction was minimized by changing the mode of addition of the aldehydes to the isopropoxide solution. The aldehydes were not introduced instantaneously at the start of the experiment, but at a uniform rate throughout the reduction process. This operating procedure enables the yield of alcohols to be increased (Table 2, Expts. 4-7) by an average of 10%, and the consumption of catalysts to be decreased. This is apparently because, at each instant there is available the excess of aluminum isopropoxide necessary for complete reduction; this excess is formed by exchange reaction between the aluminates of the C_6 to C_8 alcohols, which are formed, and the excess of isopropyl alcohol.

$$R_1-CH_2-O\frac{Al}{3} + CH_3-CHOH-CH_3 \rightleftarrows R_1-CH_2OH + CH_3-CH-CH_3$$
$$O\frac{Al}{3}$$
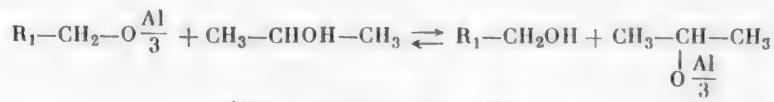
where $R_1 = C_5H_{11}, C_6H_{13}, C_7H_{15}.$

Further lowering (to 0.12 equiv.) of the quantity of catalyst taken for the reaction sharply affects the yield of C_6–C_8 alcohols (Expts. 8 and 9). Evidently, a certain proportion of the isopropoxide is decomposed by traces of water and organic acid, and the remaining quantity is insufficient for efficient reduction.

It should be noted that the reduction of aldehydes in presence of aluminum alkoxides goes relatively slowly, evidently due to the nonionic character of the reaction.

It appeared of interest to study the velocity of reduction. With this objective, a mixture of aldehydes and 0.5 equiv. aluminum isopropoxide in isopropyl alcohol was heated 30 min at the boiling point of the reaction mixture, the resulting acetone being distilled off continuously and analysis being carried out at definite intervals of time (see diagram, curve 1). The data permit the conclusion that reduction of the aldehydes goes to the extent of 70-80% in the course of 6-8 hr; the process then decreases in intensity and goes very slowly. Our

investigations showed that the velocity of reduction can be considerably increased by uniform addition of the aldehydes to the aluminum alkoxide solution instead of following the procedure, recommended in the literature, of using a previously prepared mixture of aldehydes and alkoxides. In the present case, under otherwise identical conditions, the reaction goes to the extent of 73% in 2 hr (see diagram, curve 2). The acetone resulting from the reaction is present in the amount of about 5-10% in the mixture with isopropyl alcohol and C_5-C_7 hydrocarbons. It is isolated in the pure form nearly quantitatively in a 30-40 plate column.

We thus established the following optimum conditions for reduction of C_6-C_8 aldehydes, with the help of aluminum isopropoxide: utilization as feedstock of an oxo synthesis catalyzate containing 0.002-0.007% cobalt in the form of carbonyls; uniform feeding of the aldehydes to the aluminum isopropoxide solution; continuous distillation of the acetone; average equivalent ratio of aldehyde to aluminum isopropoxide of 1:0.5 and 1:0.25. The alcohol yield under these conditions is 94% calculated on the aldehyde reacted, the acetone yield is 95%, and the consumption of aluminum isopropoxide, calculated as aluminum, is 1.4-3.0% calculated on the alcohols and ketones.

We employed these optimum conditions in the reduction with aluminum sec-butoxide in a medium of sec-butyl alcohol (Table 3). Uniform addition of oxo synthesis aldehydes to a boiling solution of the sec-butoxide (0.5 equiv.) in sec-butyl alcohol gave a yield of 86-91% C_6-C_8 alcohols and a 90-95% yield of methyl ethyl ketone (Table 3).

EXPERIMENTAL

Starting Substances

1. Hydrocarbon solutions obtained after oxo synthesis (oxo synthesis catalyzate) containing (wt. %) 28-36 C_6-C_8 aldehydes, 1-9 C_6-C_8 alcohols, 9-15 esters, 0.002-0.007 cobalt carbonyls (calculated as cobalt).

2. A concentrated aldehydes fraction, boiling in the 65-85° range, from the oxo synthesis catalyzate, and containing 89-95% aldehydes.

3. Aluminum isopropoxide and sec-butoxide.

Aluminum alkoxides were prepared by Lund's method [13] with slight modifications. 0.5 g mercuric chloride and 27 g aluminum wire (previously treated with alkali solution and washed with alcohol) were placed in 300 ml of the anhydrous alcohol. The mixture was refluxed in a flask and 2 ml carbon tetrachloride, and a crystal of iodine were added. As soon as hydrogen started to come off, the heating was stopped, but it was renewed when the reaction slowed down. After complete solution of the aluminum, unreacted alcohol was at first distilled off from the reaction mixture in a low vacuum, and afterward the aluminum alkoxide was distilled off at a residual pressure of 8-13 mm. A molar solution of aluminum alkoxide in the corresponding alcohol was used in the work.

Analysis of Starting Substances

C_6-C_8 aldehydes were determined by the hydroxylamine method, esters by saponification with alcoholic alkali (with later determination of the quantity of alkali neutralizing the organic acid resulting from the saponification), carboxylic acids by titration with 0.1 N NaOH, and cobalt carbonyls by colorimetric evaluation of an acetone solution of cobalt nitrite (the presence or absence of cobalt was qualitatively checked by spectrography). It was impossible to determine the content of alcohols accurately since the acetylation method gives too high results in presence of a large quantity of aldehydes. Their amount was calculated as the difference between the weight of substance taken for the experiment (after deducting the hydrocarbons) and the sum of the aldehydes, acids, and esters found in the product.

Reduction Procedure

Into a half-liter flask were charged 50 ml of molar aluminum isopropoxide solution in 150 ml anhydrous isopropyl alcohol and 105 g of oxo synthesis catalyzate (Table 2, Expt. 2). The flask was connected to a Hahn dephlegmator, into the inner reservoir of which was poured acetone to a depth of 2 ml. The reaction mixture was heated on an oil bath to 105-110° in order to effect slow distillation of the acetone, together with the hydrocarbons and isopropyl alcohol. Reduction was continued until a negative reaction for acetone was obtained with 2,4-dinitrophenylhydrazine, and then the bath temperature was raised to 135°. At the conclusion of the reaction

the residual isopropyl alcohol was distilled off, and the flask content was hydrolyzed with 20% hydrochloric acid solution and subjected to distillation with steam. The oily layer of distillate, and the oily residue from the distillation flask were separated from water, dried with anhydrous sodium sulfate, and analyzed for their content of alcohols and unreacted aldehydes. There were obtained 44.3 g dry, oily layer, which contained 1.8% aldehydes and 77% alcohols, and 10.4 g oily residue which contained traces of aldehydes and 20% alcohols. The alcohols in the products were determined by acetylation with acetic anhydride and pyridine followed by titration of the acetic acid.

For characterization of the alcohols, the dried product (40 g) was fractionated at a residual pressure of 3 mm and the alcohols in each fraction were determined and their average molecular weights were found by the cryoscopic method: 1st, 60-90°, 30 g, alcohols content 93.5%, $M_{aver.}$ 123; 2nd, 90-110°, 4.2 g, alcohols content 13.3%, $M_{aver.}$ 200; residue 3.7 g containing 13.8% alcohols. During the reaction, 15.5 g acetone came over with isopropyl alcohol and C_5-C_7 hydrocarbons (5% solution).

A large number of the experiments (Table 1, Expts. 1-11; Table 2, Expts. 4-9) were performed by our modified procedure (with uniform rate of addition of aldehydes to the reaction mixture).

To 50 ml of molar solution of the isopropoxide in 50 ml isopropyl alcohol, heated to boiling, was added 96 g oxo synthesis catalyzate in 150 ml alcohol at a uniform rate in the course of 24 hr* (Table 1, Expt. 7). As the result of the reaction 46 g dried, oily layer was obtained, and 5 g residue (free of alcohols). The oily layer was fractionated (5 mm) to give two fractions: 1st, 65-90°, 37.1 g, 98% alcohols, $M_{aver.}$ 118; 2nd, 90-150°, 5.1 g, 28% alcohols, $M_{aver.}$ 180; residue 1.7 g.

During the reaction, 16.2 g acetone was collected in 10% solution.

Separation of Acetone from the Alcoholic Hydrocarbon Solution

Rectification was performed in a 30-40 plate column, and 95% of the acetone content was recovered.

SUMMARY

1. A method was worked out for coproduction of C_6-C_8 alcohols and ketones (acetone and methyl ethyl ketone) from oxo synthesis aldehydes and secondary alcohols in one stage in presence of aluminum alkoxides.

2. It was shown for the first time that cobalt carbonyls activate the process of reduction, and that the activity of the carbonyls is higher when use is made directly of oxo synthesis aldehydes instead of an artificially prepared mixture.

3. It was established that the process of formation of alcohols is favored by addition of aldehydes at a uniform rate to the aluminum alkoxide solution, and also by continuous distillation of the ketones formed at the same time. This procedure also inhibits condensation reactions of the aldehydes.

4. Optimum conditions were worked out in the laboratory for reduction of C_6-C_8 aldehydes in presence of aluminum isopropoxide. Under these conditions, the yield of C_6-C_8 alcohols (calculated on the reacted aldehydes) is 94%, and that of acetone is 95%; the consumption of aluminum is 1.4-3% of the alcohols and acetone produced.

5. Using aluminum sec-butoxide in sec-butyl alcohol solution, the oxo synthesis C_6-C_8 aldehydes are reduced to alcohols in a yield of 89% (on the aldehydes reacted) and the yield of methyl ethyl ketone is 93%.

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* Similar results were obtained when the solution of the aldehydes was added over a period of 6 hr or 1 hr.

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FERRIC HYDROXIDE AS A CATALYST FOR THE CONDENSATION
OF ACETONE TO DIACETONE ALCOHOL

S. A. Levina, N. F. Ermolenko and V. I. Pansevich-Kolyada

Institute of Chemistry, Academy of Sciences, Belorussian SSR

Diacetone alcohol (4-hydroxy-4-methyl-2-pentanone) is obtained by condensation of acetone in presence of catalysts. Hydroxides of alkali metals [1-4], of calcium [5,6], and of barium [7] and certain other substances [8,9], have been used as catalysts.

In the present work, we used suitably prepared ferric hydroxide [10] for this purpose. It was synthesized by the generally accepted laboratory method [11].

Use was made of four specimens of ferric hydroxide prepared by ammoniacal precipitation from ferric sulfate under various conditions. The structure of the specimens was determined, and they were compared with barium hydroxide in respect to catalytic activity.

EXPERIMENTAL

Preparation of the Catalyst

225 g $Fe_2(SO_4)_3 \cdot 9H_2O$ was dissolved in 400 ml distilled water. The solution was filtered and divided into four portions of 120 ml each. Temperature of solution before precipitation — 19°. Precipitation of ferric hydroxide was performed with the help of ammonia solution (d 0.946), diluted with water (1:1), by the following methods.

1. In the course of 30 min, 92 ml ammonia was added dropwise with constant stirring to 120 ml of $Fe_2(SO_4)_3$ solution (specimen I).

2. 92 ml ammonia was added quickly to 120 ml of $Fe_2(SO_4)_3$ solution (specimen II).

3. 120 ml $Fe_2(SO_4)_3$ solution was added quickly to 92 ml ammonia (specimen III).

4. 120 ml $Fe_2(SO_4)_3$ solution was added dropwise with constant stirring to 92 ml ammonia.

The hydroxide samples were filtered, washed until the wash water was free of $SO_4^{\bullet}$ ion (test with $BaCl_2$), dried in the air, and analyzed for moisture content and for the content of iron (bismuthate method) and $SO_4^{\bullet}$ ion.

The specific surface and the structure of the specimens were determined by the method of adsorption of CCl_4 vapor in a vacuum apparatus containing a McBain quartz balance. Analytical data and characteristics of the ferric hydroxide specimens are set forth in Table 1.

The analyses indicate that a considerable amount of $SO_4^{\bullet}$ ion is present, except in specimen 2. The gel evidently retains considerable quantities of $SO_4^{\bullet}$ ion in the process of formation of ferric hydroxide, and these ions are not easily removed by washing. This is particularly striking in specimen III, which was prepared by rapid addition of the iron salt solution to the ammonia solution. Absorption of $SO_4^{\bullet}$ ions by hydroxides has been previously noted [12]. The iron content of the pure hydroxide should be 52.25%. The slightly low value for specimens I, III, and IV can be attributed to absorption of $SO_4^{\bullet}$ ions. Concerning specimen II, a compound of the type of FeO(OH) may have been formed in addition to $Fe(OH)_3$ and, therefore, the iron content is slightly high [13].

TABLE 1

Characteristics of the Catalyst

Specimen number	Moisture content (%)	SO$_4^-$ (%)	Fe$^{\cdots}$ (%)	Pore volume (ml/mg)			Specific surface (by method of CCl$_4$ vapor adsorption (m^2/g)
				total	fine	inter-connecting	
I	10.4	3.29	49.9	0.1127	0.1020	0.0147	64
II	11.4	0.08	58.5	0.1686	0.1160	0.0360	149
III	13.5	9.60	49.1	—	—	—	9
IV	21.0	2.52	50.0	0.1470	0.1000	0.0470	141

TABLE 2

Transformation of Acetone into Diacetone Alcohol

Catalyst	Percent transformation	Period of transformation (hrs)	Velocity constant $\cdot 10^{-4}$
Ba(OH)$_2$	21.95	25	2.68
Fe(OH)$_3$ I	18.30	26	1.98
Fe(OH)$_3$ II	45.36	27	5.66
Fe(OH)$_3$ III	6.22	29	0.06
Fe(OH)$_3$ IV	23.71	28	2.03

TABLE 3

Velocity Constants of the Reaction at Various Temperatures

Temperature	Velocity constant $\cdot 10^{-4}$
55°	5.66
40	2.90
30	1.66
20	0.98
15	0.76
10	0.60

Investigation of the structure and specific surface, by the method of adsorption of CCl$_4$ vapor in a vacuum apparatus containing a McBain balance, showed that all of the specimens except II possess a finely porous structure. In the classification of A. V. Kiselev [14], their isotherms are of the third structural type, i.e., the type characteristic of homogeneous − finely porous adsorbents (Fig. 1). In their form they resemble the isotherms obtained for adsorption of aliphatic alcohol vapors on Fe(OH)$_3$ gel [15, 16]. The pore radii were calculated on the basis of the desorption branches of the isotherms, and pore-size distribution curves were plotted (Fig. 2). The latter show that the effective pore radius in specimens I, II, and IV must be 15 A, i.e., the specimens are finely porous and contain an insignificant number of interconnecting pores. As we see from Table 1, specimen II has the largest pore volume. The number of connecting pores increases insignificantly in passing from specimen I to IV. Specimen III was completely nonporous. A hysteresis loop is absent from the adsorption isotherm. It is characterized by an extremely low active surface. The specimens can be arranged in the following order in respect to the magnitude of the specific surface: II > IV > I > III (Table 1). It should be noted that the presence of contaminating SO$_4^-$ ions in the specimens of course lowers their active surface considerably, the SO$_4^-$ ions being adsorbed on the active centers. The specimens can be arranged in the reverse order with respect to the number of adsorbed SO$_4^-$ ions. Rapid addition of ammonia solution to the ferric sulfate solution evidently leads to a hydroxide with minimum SO$_4^-$ ion content and maximum specific surface. The reverse order of addition leads to a hydroxide containing much SO$_4^-$ ion, and completely devoid of activity.

A study was made of the adsorptive activity of the ferric hydroxide specimens for acetone vapor. For this purpose, a weighed sample of adsorbent was placed in a desiccator, on the floor of which was a layer of acetone. After 24 hr, the hydroxide had become moist; subsequently, a layer of liquid appeared over it and steadily increased in size. The phenomenon of isothermal transfer was observed. On investigation, this liquid was found to be a solution of diacetone alcohol in acetone. In this manner, we established, for the first time, the catalytic activity of ferric hydroxide in the condensation of acetone to diacetone alcohol [10].

Preparation of Diacetone Alcohol

A filter paper cartridge containing 2 g of catalyst was placed in a modified Soxhlet apparatus, in which flooding of the extractor was effected continuously instead of periodically. 20 g acetone was poured into the
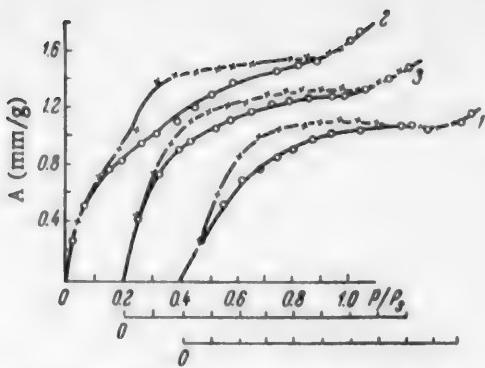
Fig. 1. Isotherms of adsorption of CCl_4 vapor on specimens of ferric hydroxide. $Fe(OH)_3$ specimens: 1) I; 2) II; 3) IV. A (mm/g) is the adsorption in millimoles per gram of adsorbent; P/P_s is the relative pressure.
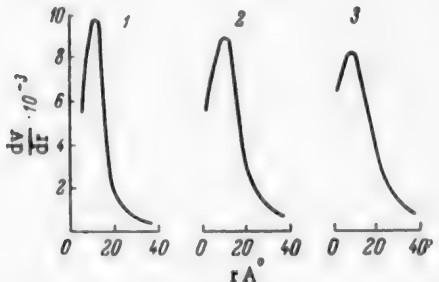

Fig. 2. Pore-size distribution curves. Ferric hydroxide specimens: 1) I; 2) II; 3) IV; dv/dr is the change of pore volume with change of radius of the pores; r is the radius of the pores in angstroms.
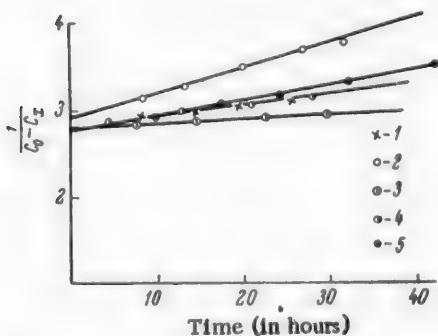

Fig. 3. Relation between $1/(c_0 - c_X)$ and reaction period. 1) to 4) Specimens of $Fe(OH)_3$; 5) $Ba(OH)_2$. c_0 is the initial concentration of acetone in moles; c_X is the concentration of the diacetone alcohol formed in moles.

50-ml flask of the apparatus and heated on a water bath with continuous stirring to $65 \pm 0.2°$. Catalysis temperature $55 \pm 0.5°$. The product of condensation of acetone in presence of ferric hydroxide is a yellow liquid with a faint odor. After unreacted acetone had been distilled off, the reaction product was fractionated in vacuo to give a colorless liquid with b.p. $43°$ (1 mm), $n^{20}D$ 1.4240, d^{20}_4 0.9420, MR_D 31.44; calc. 31.43.

These data characterize the substance as diacetone alcohol.

We also studied the kinetics of formation of diacetone alcohol in presence of barium hydroxide and of specimens of ferric hydroxide. At predetermined intervals of time we determined the concentration of diacetone alcohol with the help of the interferometer. Prolonged boiling led to partial evaporation of acetone. Therefore, before the determination of the concentration, the flask containing the reaction product was weighed and a deficiency of acetone was added. A calibration curve was plotted from solutions of diacetone alcohol in acetone.

Formation of diacetone alcohol is a bimolecular reaction. In Table 2 are set forth data for the transformation of acetone into diacetone alcohol after 25-28 hr in presence of $Ba(OH)_2$ and specimens of $Fe(OH)_3$. The velocity constants are also given.

We see from Table 2 that the percent transformation in presence of specimen II is twice as high as in presence of $Ba(OH)_2$, and that the velocity constant with this specimen is two and more times higher than with barium hydroxide, which is usually employed for synthesis of diacetone alcohol, both in the laboratory and in industry [17].

The catalytic activity of the specimens of catalyst altered in the same order as the adsorptive activity: II > IV > I > III. Specimens with higher surface activity are more active catalytically.

The linear relation between $1/(c_0 - c_X)$ and reaction period, which characterizes a bimolecular reaction, is illustrated in Fig. 3 where c_0 is the initial concentration and c_X is the concentration of the product formed.

The velocity constant of the reaction at two temperatures (40 and 55°) was determined for the most active specimen, II, using the apparatus illustrated in Fig. 4. The latter comprises a small flask a connected to a condenser, and a reaction vessel b which contains the catalyst and a thermometer. The flask was placed in a water bath at $65 \pm 0.1°$. The
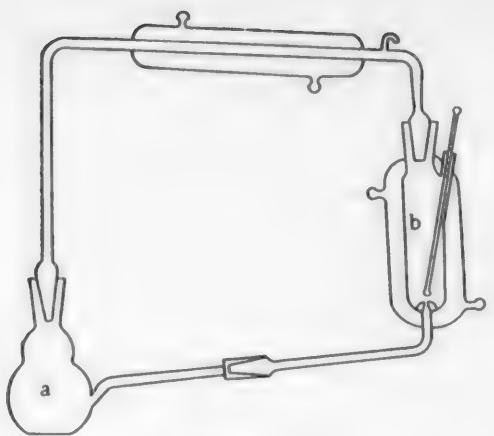
Fig. 4. Apparatus for measurement of the velocity constant of the conversion of acetone to diacetone alcohol at various temperatures.

reaction vessel was fixed in a glass jacket connected to an ultrathermostat for maintenance of the appropriate temperature of the catalyzate. Acetone vapor from the flask condensed in the condenser, and acetone entered the reaction vessel. From the latter, the catalyzate returned to the flask.

The activation energy was calculated by the Arrhenius equation on the basis of the velocity constants of the reaction. It is 9100 cal/mole. The low value bears witness to the catalytic character of the process under investigation.

Velocity constants for various temperatures, calculated on the basis of the activation energy, are presented in Table 3.

The reaction velocity is seen to increase with rising temperature.

SUMMARY

1. Depending upon the method of preparation, it is possible to obtain ferric hydroxides differing in adsorptive and catalytic activities. The activity increases with falling content of SO_4^- ions.

2. The possibility of using ferric hydroxide as a catalyst for the condensation of acetone to diacetone alcohol was established.

3. The velocity constant of the condensation reaction in presence of ferric hydroxide (specimen II) is twice as high as in presence of barium hydroxide.

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ETHERS CONTAINING AN ALLYLIC DOUBLE BOND

V. ETHERIFICATION OF FURFURYL ALCOHOL WITH $\alpha,\alpha,\gamma,\gamma$-SUBSTITUTED ALLYL ALCOHOLS

V. I. Pansevich-Kolyada

Belorussian Polytechnic Institute

Original article submitted May 22, 1958

Very few ethers of furfuryl alcohol are known. An obstacle to their preparation is undoubtedly the facility of cleavage of the furan ring in an acid medium, especially when heated — the most usual conditions for preparation of ethers.

Only 4 ethers of furfuryl alcohol have been reported in the literature: the methyl, ethyl, n-propyl, and isoamyl ethers, which were obtained by heating of a mixture of furfuryl alcohol and the appropriate alkyl iodide with solid potassium hydroxide [1]. The methyl and ethyl ethers of alkyl- and arylfurylcarbinols [2-5], and the methyl ether of diphenylfurylcarbinol [2] are known. These ethers are obtained by the action of a solution of hydrogen chloride in the corresponding alcohol on solutions of the alkyl- or arylfurylcarbinols at room temperature, sometimes for a considerable period. They are also formed as intermediates in the transformation of alkyl- and arylfurylcarbinols under the action of hydrogen chloride, which results in opening of the furan ring and formation of esters of homologs of levulinic acid [2-6]. Ethers of alkyl- and arylfuryl carbinols are formed by condensation of alcoholates of these alcohols with dimethyl- and diethylaminoethyl chloride [7]. Ethers of the ketal type containing the 2,5-dihydrofuran ring are also formed by short-period heating of some hydroxydihydrofurans with methyl or ethyl alcohol in presence of a few drops of concentrated acetic acid [8,9].

As was shown in the preceding communications [10-12], the $\alpha,\alpha,\gamma,\gamma$-substituted allyl alcohols that we studied very easily form ethers in good yields under mild conditions. Etherification of these alcohols only occurs in reaction with primary alcohols of the aliphatic and aromatic series, with glycol, with glycerol, and with other substances containing a primary alcohol group.

In the present work, we exploited this characteristic of tetrasubstituted allyl alcohols for the etherification of furfuryl alcohol.

The action of a small quantity of dilute sulfuric acid on solutions of 2,4-dimethyl-2-penten-4-ol (I), 2,4-dimethyl-2-hexen-4-ol (II), 2,4-dimethyl-2-hepten-4-ol (III), 2,4-dimethyl-2-octen-4-ol (IV), 2,4,7-trimethyl-2-octen-4-ol (V), and 2-methyl-4-phenyl-2-penten-4-ol (VI) in furfuryl alcohol (VII) leads to formation of ethers of furfuryl alcohol and $\alpha,\alpha,\gamma,\gamma$-tetrasubstituted allyl alcohols of the following structure:

$$CH_3-C=CH-\underset{\underset{CH_3}{|}}{\overset{\overset{CH_3}{|}}{C}}-O-CH_2-\overset{HC-CH}{\underset{O}{\overset{\parallel \quad \parallel}{C \quad CH}}}$$

(VIII) R = CH₃, (IX) R = C₂H₅, (X) R = n-C₃H₇,
(XI) R = n-C₄H₉, (XII) R = iso-C₅H₁₁, (XIII) R = C₆H₅.
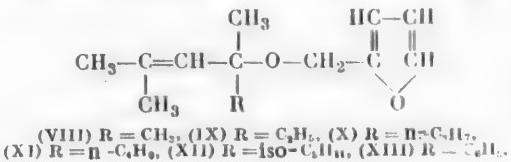
No substances other than ethers (VIII)-(XIII) were found among the products of the reaction. The furan ring is therefore not opened under the specified conditions.

Characteristics of the Prepared Ethers

Ether	Boiling point (pressure in mm)	n_D^{20}	d_4^{20}	MR_D		Found (%)		Empirical formula	Calc. (%)	
				found	calc.	C	H		C	H
2,4-Dimethyl-4-furfuryloxy-2-pentene (VIII)	78—78.5° (2)	1.4750	0.9544	57.23	57.30	73.90	9.45	$C_{12}H_{18}O_2$	74.19	9.34
2,4-Dimethyl-4-furfuryloxy-2-hexene (IX)	101—102 (2)	1.4752	0.9529	61.52	61.92	74.88	9.68	$C_{13}H_{20}O_2$	75.00	9.61
2,4-Dimethyl-4-furfuryloxy-2-hexene (X)	116—118 (5)	1.4755	0.9477	66.02	66.54	75.78	10.05	$C_{14}H_{22}O_2$	75.67	9.91
2,4-Dimethyl-4-furfuryloxy-2-octene (XI)	124—126 (4.5)	1.4739	0.9380	70.75	71.15	76.06	10.29	$C_{15}H_{24}O_2$	76.21	10.24
2,4,7-Trimethyl-4-furfuryloxy-2-octene (XII)	119—120 (1.5)	1.4746	0.9362	75.13	75.77	76.58	10.29	$C_{16}H_{28}O_2$	76.74	10.47
2-Methyl-4-phenyl-4-furfuryloxy-2-pentene (XIII)	155—158 (2)	1.5408	1.0507	76.54	76.79	79.50	7.69	$C_{17}H_{20}O_2$	79.63	7.87

EXPERIMENTAL

$\alpha, \alpha, \gamma, \gamma$-Tetrasubstituted allyl alcohols (I)–(VI) were synthesized from mesityl oxide (4-methyl-3-penten--2-one) and the appropriate organomagnesium compounds (10-16).

Preparation of ethers. The $\alpha, \alpha, \gamma, \gamma$-tetrasubstituted allyl alcohol was mixed in a small flask with freshly vacuum-distilled furfuryl alcohol taken in a quantity slightly larger than that theoretically required. 1-2 ml of aqueous solution of sulfuric acid (1:5) was then stirred in. This resulted, except in the case of ethers (VIII) and (IX), in development of a red color [especially during preparation of ether (XIII)]. After a short time, the temperature of the mixture rose by 5-6°. The mixture became cloudy and deposited a small layer of water, after which the temperature usually fell. A little water and ethyl ether were added to the mixture. The ethereal layer was separated and dried with magnesium sulfate and a little potassium carbonate. The ethyl ether and unreacted furfuryl alcohol were distilled off in vacuo. The reaction product was next distilled. The yield of ethers was good, except that of ether (XIII). They are all soluble in organic solvents and decolorize permanganate solution. Their physical constants and analytical data are set forth in the table.

2,4-Dimethyl-4-furfuryloxy-2-pentene (VIII). Reaction components were 34.2 g alcohol (I), 39.2 g alcohol (VII) and 1 ml H_2SO_4. Yield 25.2 g ether in the form of a colorless liquid, which slowly turned yellow when kept. Yield 73%.

2,4-Dimethyl-4-furfuryloxy-2-hexene (IX). 17 g alcohol (II) was dissolved in 30 g alcohol (VII) and 1 ml sulfuric acid was added. There was obtained 12.8 g ether in the form of an oily liquid which was colorless at first, but turned yellow when kept. Yield 75%.

2,4-Dimethyl-4-furfuryloxy-2-heptene (X). Components were 22 g alcohol (III), 30 g furfuryl alcohol, and 2 ml H_2SO_4. The solution became dark red. Working-up by the above procedure gave 17.4 g ether in the form of a yellowish, oily liquid which acquired an orange color on keeping. Yield 79%.

2,4-Dimethyl-4-furfuryloxy-2-octene (XI). 33 g alcohol (IV) was mixed with 60 g alcohol (VII), and 1.5 ml sulfuric acid was run in. The mixture at once turned red, the temperature rose from 15 to 21°, and the liquid became cloudy. There was obtained 26.5 g oily, straw-colored liquid which became red on keeping. Yield of ether 80%.

<u>2,4,7-Trimethyl-4-furfuryloxy-2-octene (XII).</u> There were taken 10 g alcohol (V), 15 g alcohol (VII), and 2 ml H_2SO_4; the temperature rose from 17 to 24°, and after an hour the mixture began to darken. Water and ethyl ether were added, and the mass was worked up as above. There was obtained 6.5 g ether in the form of an oily, red liquid. Yield 65%.

<u>2-Methyl-4-phenyl-4-furfuryloxy-2-pentene (XIII).</u> 10 g alcohol (VI) was dissolved in 15 g alcohol (VII) and 1 ml sulfuric acid was added. The mixture at once turned vivid red and the temperature rose from 18 to 20.5°. The color disappeared when the mass was washed with water, but reappeared on drying. There was obtained 3.2 g (32%) ether in the form of a dark-red, oily liquid.

SUMMARY

1. Furfuryl alcohol is found to easily undergo etherification with α, α, γ, γ -tetrasubstituted allyl alcohols in presence of a small quantity of aqueous sulfuric acid at room temperature.

2. Six ethers of furfuryl alcohol, not described in the literature, were prepared by this method: 2,4-dimethyl-4-furfuryloxy-2-pentene, 2,4-dimethyl-4-furfuryloxy-2-hexene, 2,4-dimethyl-4-furfuryloxy-2-heptene, 2,4-dimethyl-4-furfuryloxy-2-octene, 2,4,7-trimethyl-4-furfuryloxy-2-octene, and 2-methyl-4-phenyl-4-furfuryloxy-2-pentene.

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THE SYNTHESIS OF 1,1'-DINAPHTHYL-8,8'-DICARBOXYLIC ACID FROM NAPHTHALIMIDE

A. P. Karishin and D. M. Kustol

Poltav State Institute of Pedagogy

Original article submitted February 3, 1958

1,1'-Dinaphthyl-8,8'-dicarboxylic acid is extensively employed in industry for the synthesis of dyes of the anthanthrol series.

We know from the literature [1] that the starting substance for its industrial synthesis is 1-naphthylamine--8-sulfonic acid. Transformation of the latter into 1,1'-dinaphthyl-8,8'-dicarboxylic acid necessitates a number of complex and inconvenient operations.

This acid can be obtained considerably more simply by starting from naphthalimide, which is very readily accessible [2]. The literature describes a method for the transformation of naphthalimide into the lactam of 1--amino-8-naphthoic acid (naphthostyrene) in 56.5% yield, and for transformation of the latter into 1,1'-dinaph-thyl-8,8'-dicarboxylic acid in 38.5% yield, reckoned on the naphthalimide [3].

We worked out a method of transformation of naphthalimide into 1,1'-dinaphthyl-8,8'-dicarboxylic acid in a yield of about 72% without separation of the lactam of 1-amino-8-naphthoic acid.

EXPERIMENTAL

Hypochlorination of naphthalimide. 4.7 g naphthalimide, 100 ml water, and 12 ml 30% potassium hydroxide solution were charged into a 250-300 ml round-bottomed flask. The mixture was boiled until the naphthalimide had dissolved. The solution was cooled, and a mixture of 12 ml 30% potassium hydroxide solution, and 36 ml freshly prepared sodium hypochlorite (prepared by Raschig's method [4]) was added. The mass was stirred 2 hr and the temperature was not allowed to rise above 25-26°. The initially precipitated crystals dissolved completely after this period. Unreacted hypochlorite was decomposed by addition of sodium sulfite solution. The resulting solution contained about 0.02 mole (84%) of 1-amino-8-naphthoic acid in the form of the potassium salt.

Preparation of the diazonium salt of 1-amino-8-naphthoic acid. The solution of potassium salt of 1-amino--8-naphthoic acid was introduced into a half-liter beaker, fitted with stirrer, containing 34 ml 30% sulfuric acid. The temperature was not allowed to rise above 50° during this operation. Toward the end, the reaction mixture was strongly acidic. The resulting mixture was cooled to −4 to 0° and 1.5 g sodium nitrite dissolved in 10 ml water was added in the course of 8-10 min, after which the stirring was continued for another 15-20 min. During the whole period, the temperature was not allowed to rise above +2°; the solution had to be acidic (positive test for nitric acid). After completion of the reaction, the diazotized solution was neutralized with saturated sodium carbonate solution until weakly acidic to Congo.

Diaryl condensation and separation of 1,1'-dinaphthyl-8,8'-dicarboxylic acid. With energetic stirring, the prepared suspension of diazonium salt was added in the course of 1-2 min to a solution containing 4.25 g cuprous chloride, 2.64 g sodium bicarbonate, 15 ml 28% ammonia solution, and 30 ml water. The mixture was stirred 30-40 min at 10-15°, and then filtered. On the filter remained 0.55 g precipitate containing 0.2 g of unreacted lactam of 1-amino-8-naphthoic acid. An excess of 50% sulfuric acid solution was added to the filtrate, and the

precipitate was filtered, washed with water, and dried. Yield 3.35 g of yellow product containing 2.93 g 1,1'--dinaphthyl-8,8'-dicarboxylic acid (determined by conversion to anthanthrone), equal to 72% on the naphthalimide taken into reaction and 75% on the naphthalimide reacted.

Preparation of a solution of the potassium salt of 1-amino-8-naphthoic acid by the action of gaseous chlorine on an alkaline solution of naphthalimide. 19.7 g naphthalimide and 1 liter of 6% potassium hydroxide solution were put into a round-bottomed one-and-a-half-liter flask equipped with a stirrer. The mixture was heated to the boil. After cooling to 15°, 9.5 g gaseous chlorine was passed in the course of 30 min into the resulting solution, with vigorous stirring. The temperature of the solution was not allowed to rise above 17°. After passage of chlorine had ceased, stirring was continued for an hour at the same temperature. The excess of chlorine was bound by addition of 22 ml 1 N sodium sulfite solution. The resulting solution could be used for preparation of 1,1'-dinaphthyl-8,8'-dicarboxylic acid by the method described above.

For preparation of the free lactam of 1-amino-8-naphthoic acid, the above solution was poured into 70 ml concentrated hydrochloric acid (d 1.18) (the liquid must have an acid reaction). The solution of the hydrochloride of 1-amino-8-naphthoic acid was introduced into 280 ml saturated (16%) sodium carbonate solution and filtered. 2.35 g of unreacted naphthalimide was retained on the filter. The filtrate was neutralized with acid and boiled 5-10 min for decomposition of the hydrochloride. It was cooled to room temperature, and the resulting precipitate was filtered and treated with 200 ml 3% sodium carbonate solution while boiling for 30 min. After cooling, the precipitate was filtered and dried at 105-110°. There was obtained 12.85 g of lactam of 1-amino--8-naphthoic acid (m.p. 176-177°). Yield 76% on the total naphthalimide, and 86.2% on the reacted naphthalimide. Treatment of the sodium carbonate solution with hydrochloric acid led to deposition of 1.35 g product containing 1.18 g naphthalic anhydride (identified by conversion to naphthalimide).

SUMMARY

1. The possibility was demonstrated of preparation of 1,1'-dinaphthyl-8,8'-dicarboxylic acid from naphthalimide without isolation of the lactam of 1-amino-8-naphthoic acid. Yield 72%.

2. It was established that the lactam of 1-amino-8-naphthoic acid can be obtained by the action of gaseous chlorine on an alkaline solution of naphthalimide at 15-17°. Yield 86.2%.

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DERIVATIVES OF DICARBOXYLIC ACIDS

I. THE ALKYLATION OF THE DIETHYL ESTER OF 4-HYDROXYPHTHALIC ACID

S. I. Kanevskaya and V. B. Brasyunas

Institute of Pharmacy, Moscow and Kaunas State Institute of Medicine

Original article submitted June 29, 1958

The preparation of phenolic ethers containing long chains of carbon atoms has for long been a fairly complex problem. V. M. Rodionov and S. I. Kanevskaya [1,2] found that esters of p-toluenesulfonic acid are good alkylating agents for phenols. This method was later successfully extended to other classes of organic compounds.

We were interested in the possibility of obtaining 4-alkoxyphthalic acids in good yields. In view of the simplicity of Rodionov's method of alkylation of phenols and the high yields obtained, we attempted to use esters of p-toluenesulfonic acid for alkylation of the diethyl ester of 4-hydroxyphthalic acid. We alkylated the latter compound by heating it on a water bath for 1.5 hr with an equimolar quantity of sodium ethoxide and a 10% excess of the corresponding ester of p-toluenesulfonic acid. We found that the reaction does not go to completion: on acidification of the alkaline solution there always separates a small quantity of unchanged diethyl ester of 4-hydroxyphthalic acid (this can be used again for alkylation). Yields of pure diethyl esters of 4-alkoxyphthalic acids are 74-87% (reckoned on the ester of hydroxyphthalic acid going into reaction). After purification by vacuum distillation, the compounds are oily, straw-colored liquids (see Table 1 for constants).

The diester of 4-hydroxyphthalic acid was alkylated with alkyl halides for the purpose of comparison. Experiments showed that alkylation with alkyl iodides goes with lower yields than alkylation with esters of p-toluenesulfonic acid, but with better yields than with alkyl bromides.

The esters of 4-alkoxyphthalic acids that we synthesized were converted to the corresponding acids and imides. 4-Alkoxyphthalic acids were obtained by saponification of the esters with alcoholic alkali for 2 hr. Yield 90-93%. Recrystallization from water gave colorless substances, soluble in hot water, ethyl alcohol, and acetic acid; insoluble in benzene.

4-Alkoxyphthalic acids were converted to the corresponding imides by the amidation technique of V. M. Rodionov and A. M. Fedorova [3]. The imides form colorless crystals, poorly soluble in hot water, soluble in alcohol and acetic acid. The compounds crystallize from alcohol. Yields, melting points, and analyses of the 4-alkoxyphthalimides are set forth in Table 2.

EXPERIMENTAL

The diethyl ester of 4-hydroxyphthalic acid was synthesized by the previously described methods [4-6] with slight modifications (at the stage of reduction of the diethyl ester of 4-nitrophthalic acid). For preparation of esters of p-toluenesulfonic acid, see [7,8].

Diethyl ester of 4-nitrophthalic acid. For preparation, see [9, 10]. Yield 37%. M.p. 33-34°.

Diethyl ester of 4-aminophthalic acid. To a solution of 40 g diethyl ester of 4-nitrophthalic acid in 220 ml anhydrous alcohol was added 450 ml concentrated hydrochloric acid with stirring and cooling. This was followed by addition in small portions of 30 g zinc dust at 30-40° in the course of 2-3 hr. The mixture was stood at room temperature for 15 hr, diluted with water, neutralized with 10% sodium carbonate solution, and extracted with

TABLE 1

Alkoxy group	Yield (%)	Boiling point (pressure, mm)	d_4^{20}	n_D^{21}
CH_3O	87	156—158° (3)	1.1576	1.5155
C_2H_5O	77	161—163 (3)	1.1225	1.5099
н.-C_3H_7O	74	187—190 (6)	1.1028	1.5063
н.-C_4H_9O	78	178—181 (4)	1.0852	1.5030

TABLE 2

Alkoxy group	Yield (%)	Melting point	Formula	% nitrogen found	% nitrogen calculated
CH_3O	88	220.5—221.5°	$C_9H_7O_3N$	7.62, 7.62	7.91
C_2H_5O	89	181 —182	$C_{10}H_9O_3N$	7.00, 7.10	7.33
н.-C_3H_7O	85	154.5—155.5	$C_{11}H_{11}O_3N$	6.50, 6.63	6.83
н.-C_4H_9O	83	149.5—150.5	$C_{12}H_{13}O_3N$	6.18, 6.28	6.39

ether. After the ether had been driven off and the residue cooled, the resulting crystals were washed with alcohol. Yield 24.5 g (69%). M.p. 95-96° (from alcohol) [11].

Diethyl ester of 4-hydroxyphthalic acid was prepared as previously described [6]. Yield 89%.

Diethyl ester of 4-methoxyphthalic acid. 10.7 g diethyl ester of 4-hydroxyphthalic acid, 90 ml sodium ethoxide solution (prepared from 1.04 g sodium), and 9.2 g methyl p-toluenesulfonate were boiled 1.5 hr. After cooling, the precipitate was filtered, the solvent was taken off in vacuo, and the residue was dissolved in ether and extracted with 5% caustic alkali solution. From the ethereal layer was obtained 8.9 g diethyl ester of 4--methoxyphthalic acid, which was then distilled in vacuo. B.p. 156-158° (3 mm). Yield 8.1 g (87%). Acidification of the alkaline solution gave 1.9 g of the original diethyl ester of 4-hydroxyphthalic acid.

The esters of other 4-alkoxyphthalic acids were obtained under similar conditions. Data for the esters are set forth in Table 1.

4-Methoxyphthalic acid. 8.1 g diethyl ester of 4-methoxyphthalic acid was saponified for 2 hr with a solution of alcoholic potash (from 4.5 g potassium hydroxide and 20 ml 60% alcohol). The solvent was driven off; the residue was dissolved in water and acidified, and the precipitate was recrystallized from water. Yield 5.5 g (87%). M.p. 163-164° [12].

4-Ethoxyphthalic acid. Yield 90%. M.p. 155.5-156.5° (from water) [12].

4-n-Propoxyphthalic acid. Yield 93%. M.p. 150-151° (from water).

Found %: C 58.89; H 5.41. $C_{11}H_{12}O_5$.

Calculated %: C 58.92; H 5.39.

4-n-Butoxyphthalic acid. Yield 91%. M.p. 130-131° (from water).

Found %: C 60.59; H 5.96. $C_{12}H_{14}O_5$.

Calculated %: C 60.50; H 5.92.

4-Methoxyphthalimide. To 10 ml acetic acid was gradually added 4 g ammonium carbonate and then 4 g 4-methoxyphthalic acid. The mixture was first heated 0.5 hr at 115-130°, and then 1.5 hr at 160-180°; thereupon, 90% of the original quantity of acetic acid was distilled off. Crystals came down on cooling. These were washed with 10% sodium carbonate solution and water, and dried. Yield 3.2 g (88%). M.p. 220.5-221.5° (from alcohol) [13].

Other 4-alkoxyphthalimides were prepared under similar conditions. Data appear in Table 2.

SUMMARY

1. The alkylation of the phenolic hydroxyl of the diethyl ester of 4-hydroxyphthalic acid was studied. Alkylation with esters of p-toluenesulfonic acid by V. M. Rodionov's technique is found to go with better yields than with the help of alkyl halides.

2. It was shown that 4-alkoxyphthalic acids are amidated with good yields under the conditions of V. M. Rodionov and A. M. Fedorova.

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INVESTIGATION OF DICARBOXYLIC ACID DERIVATIVES

## II. SYNTHESIS OF CERTAIN N,N-DIETHYLAMINOALKYL-4-ALKOXYPHTHALIMIDES

S. I. Kanevskaya and V. B. Brasyunas

Moscow Pharmaceutical Institute and Kaunas State Medical Institute

Notwithstanding numerous investigations devoted to the synthesis and study of local anesthetics, the problem of searching for new anesthetics is still urgent. Local anesthetics are found among various classes of organic compounds — esters, substituted acid amides, urethanes, amidines, etc. In 1946 it was found [1] that N,N-dialkylaminoalkyl derivatives of phthalimide have mild local-anesthetic action when injected subcutaneously.

Accumulated factual material indicates that the local-anesthetic action of organic compounds is enhanced on introduction of alkoxy groups into the molecule [2-8]; this prompted us to synthesize a series of N,N-diethyl-aminoalkyl derivatives of 4-alkoxyphthalimides of the general formula:
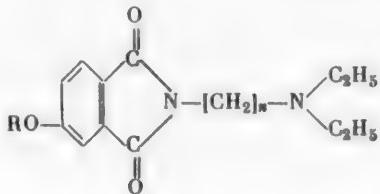
Compounds of this type may be synthesized either by fusion of the corresponding alkoxyphthalic anhydrides with diethylaminoalkylamines or by condensation of the potassium derivatives of 4-alkoxyphthalimides with diethylaminoalkyl chlorides.

Bases of N,N-diethylaminoalkyl derivatives of 4-alkoxyphthalimides were prepared by us through condensation of the potassium derivatives of 4-alkoxyphthalimides with diethylaminoalkyl chlorides. These bases were purified through the hydrochlorides; in most cases, they were crystallized, with the exception of N,N-β-diethyl-aminoethyl-4-butoxyphthalimide, which could not be obtained in crystalline form. It is an oily, yellow-brown liquid. All the other synthesized bases are light-yellow, low-melting crystalline substances, insoluble in water, and readily soluble in organic solvents. N,N-Diethylaminoalkyl-4-alkoxyphthalimides were characterized in the form of the hydrochlorides. In order to obtain the latter, the bases were dissolved in absolute ether, and alcoholic hydrogen chloride solution added. The separated hydrochlorides quickly crystallized. They are readily soluble in water and in ethyl and other alcohols, and insoluble in ether and benzene. Melting points, yields, and analytical data for all substances obtained are given in the table.

Pharmacological investigation of the compounds synthesized by us showed that our hypothesis with regard to the enhancement of the anesthetic activity on introduction of alkoxy groups into the molecule was correct. Actually, N,N-diethylaminoalkyl-4-alkoxyphthalimides (especially the propoxy and butoxy derivatives) in the form of a 0.1% solution are strong surface anesthetics, while similar derivatives which do not contain alkoxy groups (N,N-γ-diethylaminopropylphthalimide hydrochloride) are quite inactive (as surface anesthetics) even in

N,N-Diethylaminoalkyl-4-alkoxyphthalimides and Their Hydrochlorides

No.	Name	Yield (%)	Melting point of base	Melting point of hydrochloride	Formula	Found (%)				Calculated (%)			
						C	H	N	Cl	C	H	N	Cl
1	N,N-γ-diethylaminopropyl-4-methoxyphthalimide	72	40–41°C	167–168°	$C_{16}H_{22}O_3N_2 \cdot HCl$	58.64, 58.76	7.12, 7.03	8.53, 8.61	—	58.80	7.09	8.58	—
2	N,N-β-diethylaminoethyl-4-ethoxyphthalimide	48	40.5–42	164.5–165.5	$C_{16}H_{22}O_3N_2 \cdot HCl$	58.55, 58.64	7.14, 7.13	8.47, 8.50	—	58.80	7.09	8.58	—
3	N,N-γ-diethylaminopropyl-4-ethoxyphthalimide	75	35.5–37	131.5–132.5	$C_{17}H_{24}O_3N_2 \cdot HCl$	59.82, 59.80	7.49, 7.47	8.55, 8.47	10.11, 10.29	59.90	7.39	8.22	10.40
4	N,N-β-diethylaminoethyl-4-propoxyphthalimide	68	34–35.5	174.5–175.5	$C_{17}H_{24}O_3N_2 \cdot HCl$	59.98, 59.74	7.42, 7.53	8.11	10.30, 10.46	59.90	7.39	8.22	10.40
5	N,N-γ-diethylaminopropyl-4-propoxyphthalimide	64	34.5–36	136–137	$C_{18}H_{26}O_3N_2 \cdot HCl$	60.54, 60.69	7.57, 7.70	7.73	—	60.92	7.67	7.89	—
6	N,N-β-diethylaminoethyl-4-butoxyphthalimide	37	oil	142–143	$C_{18}H_{26}O_3N_2 \cdot HCl$	—	—	7.61	—	—	—	7.89	—
7	N,N-γ-diethylaminopropyl-4-butoxyphthalimide	75	25–26	112–113	$C_{19}H_{28}O_3N_2 \cdot HCl$	—	—	7.42	—	—	—	7.59	—

the form of a 1% solution. The methoxy derivative is a mild surface anesthetic. Considerable strengthening of activity is observed in the case of the ethoxy, and especially the propoxy and butoxy derivatives. Lengthening of the chain of carbon atoms in the imide part of the molecule (replacement of ethyl by propyl) leads to an increase in the duration of the anesthetizing action, but in this case the toxicity of the compounds grows. N,N-β- -diethylaminoethyl-4-butoxyphthalimide hydrochloride has the most favorable pharmacological* properties.

EXPERIMENTAL

Potassium 4-methoxyphthalimide. A 1.8 g quantity of 4-methoxyphthalimide and 90 ml of anhydrous alcohol were boiled until the solid matter was completely dissolved, a solution of 0.56 g of potassium hydroxide in 2 ml of 75% alcohol was added to the hot solution, and the latter was quickly cooled. The precipitated potassium 4-methoxyphthalimide was separated out, a second 1.8 g portion of 4-methoxyphthalimide was added to the mother liquor, and the whole process was repeated. The two portions of potassium 4-methoxyphthalimide were combined and washed with acetone. Yield 4.2 g (95%).

The potassium derivatives of other 4-alkoxyphthalimides were obtained under similar conditions. Yields varied in the range 83-96%.

N,N-γ-Diethylaminopropyl-4-methoxyphthalimide hydrochloride. A mixture of 2.15 g of potassium 4- -methoxyphthalimide, 3 g of freshly distilled diethylaminopropyl chloride, and 12 ml of anhydrous alcohol was heated for 11 hours at 90-95° in a flask provided with a reflux condenser and a calcium chloride tube. At the end of the reaction the precipitate formed was filtered out, the alcohol was distilled off in vacuo, the base was converted to the hydrochloride by being dissolved in 5% hydrochloric acid, and the solution was extracted with ether. The aqueous acid solution was filtered and neutralized to litmus with 5% alkali solution. The separated base was extracted with ether, the ethereal solution was washed with water and dried with sodium sulfate, and the ether was distilled off. N,N-γ-diethylaminopropyl-4-methoxyphthalimide gradually crystallized on cooling. Yield 2.1 g (72%), m.p. 40-41°. To obtain the hydrochloride, the base was dissolved in dry ether and alcoholic hydrogen chloride solution was added until an intense, white turbidity developed. On standing in a cooling mixture, the hydrochloride quickly crystallized. It was filtered out, washed with ether, and recrystallized twice from isopropyl alcohol; m.p. 167-168°. The substance was readily soluble in water and alcohol, and insoluble in ether and benzene.

Other N,N-diethylaminoalkyl-4-alkoxyphthalimide bases were obtained under similar conditions. In contrast to N,N-γ-diethylaminopropyl-4-alkoxyphthalimides, however, N,N-β-diethylaminoethyl-4-alkoxyphthalimides are very easily cleaved in aqueous acid solution to the corresponding 4-alkoxyphthalic acids. Therefore, only the first of them can be purified through the hydrochlorides under the conditions described above. In the case of N,N-β-diethylaminoethyl-4-alkoxyphthalimides it was expedient to convert the bases to hydrochlorides by addition of alcoholic hydrogen chloride solution and subsequent dilution with a small amount of anhydrous alcohol. Sufficient ether was then added to this solution to prevent precipitation of the hydrochlorides, after which 5% alkali solution was slowly added until an alkaline reaction was obtained with litmus. The separated bases were converted to hydrochlorides, as described above. Melting points, yields, and analytical data for the substances obtained are given in the table.

SUMMARY

A series of N,N-diethylaminoalkyl-4-alkoxyphthalimides and their hydrochlorides have been prepared through the interaction of diethylaminoalkyl chlorides and the potassium derivatives of 4-alkoxyphthalimides.

Some of the synthesized substances, in the form of 0.1% aqueous solutions, have pronounced surface-anesthetic properties. The most active of the synthesized compounds are the butoxy derivatives.

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# SYNTHETIC INVESTIGATIONS IN THE FIELD OF POLYENE COMPOUNDS

XIV. TREND OF HYDRATION OF AN ACETYLENIC BOND IN A MOLECULE CONTAINING A DIENYNE SYSTEM CONJUGATED WITH A CARBONYL GROUP

G. I. Samokhvalov, L. A. Vakulova, S. G. Mairanovskii
and L. V. Luk'yanova

All-Union Scientific Research Vitamin Institute

Original article submitted April 14, 1958

Among the natural polyenic pigments, oxygen-containing carotenoids constitute an important group. Among the marine invertebrates and algae, myxoxanthine, which has vitamin A activity, is abundant. The chemical structure of this compound has not been fully determined; besides the β-ionic ring and the polyene chain usual for carotenoids, myxoxanthine contains a cyclic [1,4] or aliphatic [2,3] grouping with a carbonyl group in position 4 [(I) or (II)]:
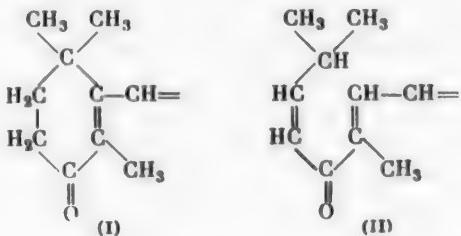
In searching for a way to synthesize this part of the molecule of the carotenoid myxoxanthine, we considered the possibility of hydrating an acetylenic aldehyde — 3,7-dimethyloctadien-2,6-yn-4-al (III) — according to the scheme (III) → (IV) → (V):
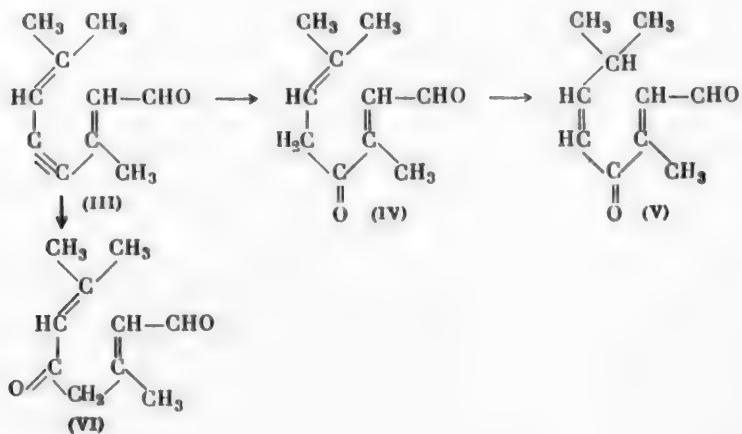
The trend of hydration toward the formation of (IV) or the product of prototropic rearrangement [5], occurring in the course of the reaction (V), may be the result of formation of an intermediate complex and a final compound stabilized by conjugation of unsaturated bonds. Furthermore, the hydration of the acetylenic bond could also be directed toward combination with isolated carbonyl groups (VI), since the hydration of acetylenic ketones and acids leads mainly to the formation of β-dicarbonyl compounds [6-8], whereas the inclusion of a

$$-CH=\overset{\overset{\displaystyle CH_3}{\textstyle |}}{C}-$$ group between the carbonyl group and the one being hydrated could not change the direction of polarization of the triple bond [9]. The effect of alkyl substituents also could facilitate the formation of (VI), since the elements of water add to the triple bond of the unsymmetrical dienynes in such a way that the oxygen becomes attached to the carbon bound to the substituted (or most substituted) vinyl radical [10,11].

3,7-Dimethyloctadien-2,6-yn-4-al (III) was synthesized according to the scheme:
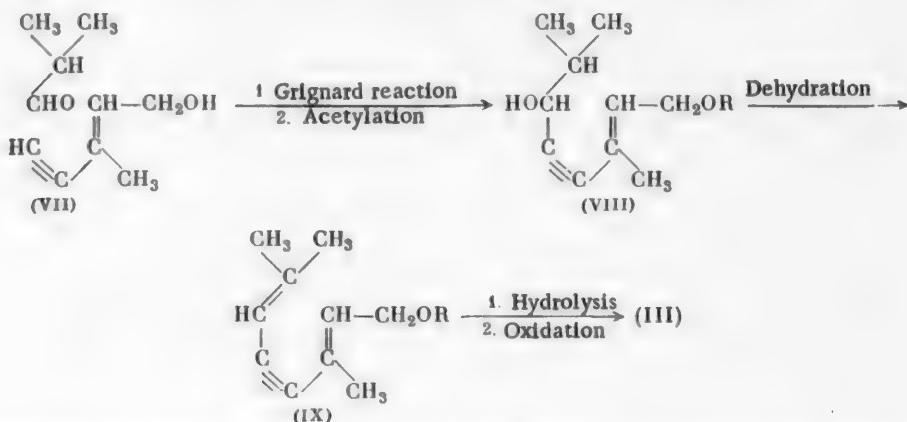
Compound (III) was hydrated by an aqueous-methanolic solution of mercuric sulfate, with cautious heating.

The first evidence in favor of the formation of (IV) or (V) is the absence of a color reaction between the hydration product and ferric chloride, since compound (VI) must be enolized. From the hydration product there is obtained a crystalline semicarbazone with m.p. 152-153°, corresponding in composition to the ketoaldehyde $C_{10}H_{14}O_2$.

For comparison of the optical and polarographic properties of the compound obtained, ketoaldehyde (XI), having a known disposition of carbonyl groups, was synthesized, and its aldehyde-derived semicarbazone (XII), m.p. 197-198°, as well as its semicarbazone with the semicarbazide radical known to be substituted into the keto group (XIV), m.p. 167-167.5°, was prepared according to the scheme:
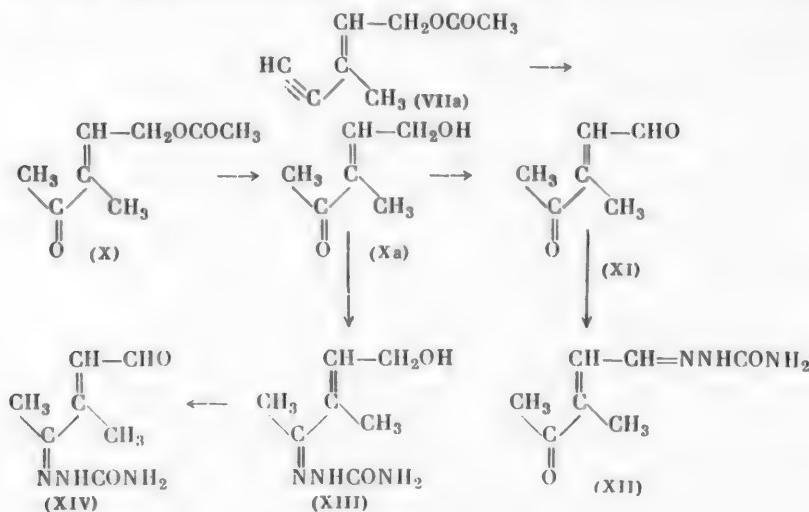
Characteristics of the Polarograms of Semicarbazones of Unsaturated Carbonyl Compounds

Semicarbazone	Wave	Buffer of pH 6		Buffer of pH 10
		$E_{\frac{1}{2}}$ *	i_{lim}/c	$E_{\frac{1}{2}}$ *
(XIV)		−0.90	~5.0	−0.90
(XII) {	Forewave	−0.90	} ~5.0	−0.90
	Main wave	−1.10		−1.11
Of the ketoaldehyde {	Forewave	−0.6-0.7	} 1.2	−0.7
being investigated {	1st wave (two inflections)	−0.9-1.1		−1.0
$C_{10}H_{14}O_2$ {	2nd wave	−1.75	3.2	−1.8
Of the 3,7-dimethyl- {	1st wave	−1.15	~0.4	−1.2
octadien-2,6-yn- -4-al (III) {	2nd wave	−1.75	4.2	−1.75

Comparison of the UV-absorption spectra of the semicarbazones of the ketoaldehyde $C_{10}H_{14}O_2$ (Fig. 1), and the simpler ketoaldehyde (XI) shows that they nearly coincide with respect to position (308 and 307 mμ, respectively), and intensity of the longwave maximum and confirms the community of structure of these compounds with respect to the mutual disposition of the carbonyl groups. Investigation of its absorbance for UV light in solvents differing considerably in polarity shows that the characteristic maxima are retained (Fig. 2), and indicates that the substance cannot be enolized.

Polarographic investigation gives additional proof of the community of structure of ketoaldehyde (XI) and the compound under investigation with respect to the mutual disposition of the carbonyl groups. The main characteristics of the polarograms obtained are given in the table and in Fig. 3.
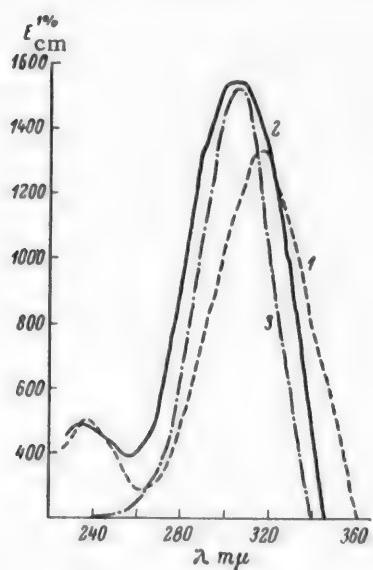

Fig. 1. Ultraviolet absorption spectra of semicarbazones (in 96% alcohol): 1) acetylenic aldehyde (III); 2) hydration product of aldehyde (III) being investigated; 3) aldehyde (XII).

The polarograms were taken at 25° (in a nitrogen atmosphere) with a recording polarograph of the S. B. Tsfasman type [16]. To eliminate oscillations of current, the capillary of the dropping electrode had a small vane for forced detachment of the drops [17]. Its open-circuit characteristics were m = 3.93 mg/sec, t = 0.18 sec, and $m^{2/3}t^{1/6} = 1.87$ mg$^{2/3}$/sec$^{-1/2}$. The anode was an external saturated calomel electrode. The work was done in two solutions prepared by diluting buffer solutions of pH 6 (citrate-phosphate) and pH 10 (borate) with methanol until the concentration of the latter was 60 vol.%.

The two semicarbazones (XII) and (XIV) of the dicarbonyl compound (XI) give clear, single-step reduction waves, the wave for semicarbazone (XII) (Fig. 3,4) having a small forewave. The half-wave potential $E_{\frac{1}{2}}$ of (XIV) (Fig. 3,5), is somewhat more positive than the $E_{\frac{1}{2}}$ of (XII), whereas the forewave potential of (XII) corresponds to $E_{\frac{1}{2}}$ for the wave of (XIV). It may be assumed that the forewave in the polarogram of (XII) is due to the reduction of a small amount of an admixture of ketone-derived semicarbazone (XIV) in the semicarbazone (XII) obtained by the reaction of semicarbazide with the free dicarbonyl compound. Calculation of the number of added electrons by means of the Ilkovic equation, on the basis of the hypothesis that the diffusion

* Relative to a saturated calomel electrode.
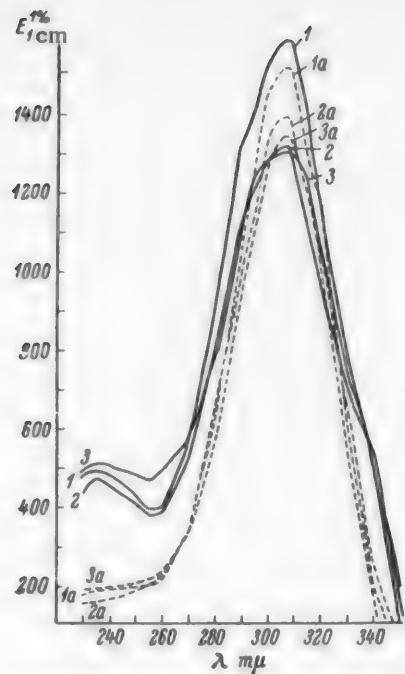
Fig. 2. UV-absorption spectra in solvents of different polarities. Semicarbazone of the hydration product of (III), under investigation: 1) in anhydrous alcohol; 2) in 2-50% alcohol; 3) in anhydrous alcohol containing 8 moles of sodium ethoxide per mole of the substance. Semicarbazone (XII): 1a, 2a, 3a) in the same solvents (respectively).
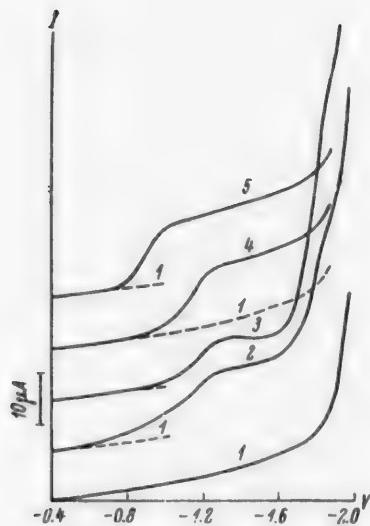
Fig. 3. Polarograms of semicarbazones in a 60% methanol solution of a buffer having a pH of 6.0 (potentials are given relative to saturated calomel electrode): 1) residual current; 2) hydration product of (III), being investigated, m.p. 152-153°, conc. 0.39 mole/liter; 3) (III), conc. 0.97 mmole/liter; 4) (XII), conc. 0.22 mmole/liter; 5) (XIV), conc. 0.25 mmole/liter.

coefficients of the molecules of semicarbazones (XII) and (XIV) in the solution under investigation are of the order of $4 \cdot 10^{-6}$ cm^2/sec, leads to the conclusion that the reduction takes two electrons. From the character of the waves for (XII) and (XIV), it may be assumed that these substances are reduced at the dropping electrode to the corresponding diols, as in the case of the reduction of unsaturated diketones [12].

The semicarbazone of the dicarbonyl compound being studied, $C_{10}H_{14}O_2$ (m.p. 152-153°), gives two reduction waves, the total height of which, with allowance for the diminished diffusion coefficient in comparison with (XII) and (XIV), corresponds to two-electron reduction. The first wave is greatly elongated (Fig. 3,2); two steps with $E_{\frac{1}{2}}$ about −0.9 and −1.1 v may be distinguished in it.

Comparison of the polarograms shows that the two steps of the first reduction wave of the semicarbazone of the compound being investigated are similar to the waves of semicarbazones (XII) and·(XIV). This indicates that the ease of addition of the first electron to a system of aldehyde and ketone groups connected by an ethylenic bond is generally the same for these compounds. The presence of two steps in the first wave for the compound being investigated, with values of $E_{\frac{1}{2}}$ coinciding with those of the first waves for (XII) and (XIV), respectively, is explained by the presence of isomers with respect to the position of attachment of the semicarbazide radical.

On reduction of the semicarbazone of the substance being investigated, only one electron is added within the limits of the first wave. The second reduction wave calls to mind the mechanism of the analogous conversion of monoaldehydes and ketones [13,14]. This is confirmed by the similarity of the polarograms of the compound being investigated and the original unhydrated one (III) (Fig. 3,3). The second reduction wave of the semicarbazone of compound (III) is identical with that of the semicarbazone of the substance being investigated, which indicates the similarity of the primary reduction products of these compounds. For all substances studied, the character of reduction does not change as the solution pH varies from 6 to 10; the half-wave potentials $E_{\frac{1}{2}}$, and the ratios between the waves remain practically unchanged, although the wave heights are slightly decreased.
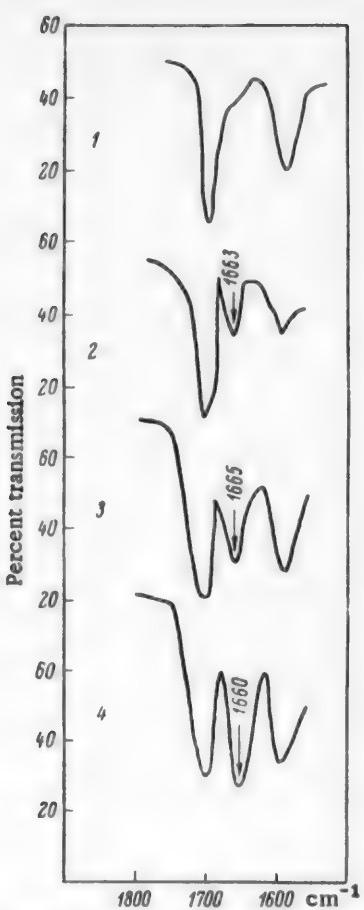
Fig. 4. IR-absorption spectra in the 1500-1800 cm^{-1} region: 1) semicarbazone of aldehyde (III); 2) semicarbazone of the hydration product of aldehyde (III); 3) semicarbazone (XII); 4) semicarbazone (XIV).
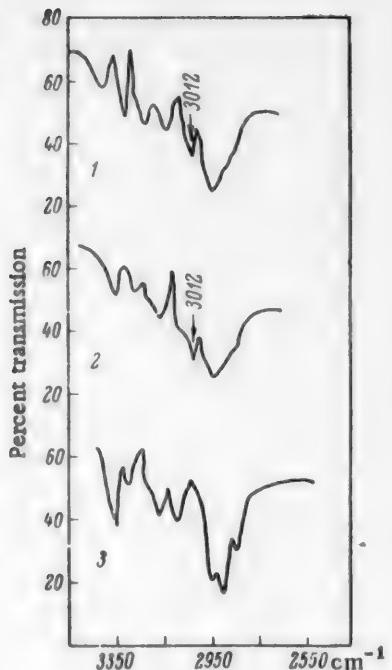
Fig. 5. IR-absorption spectra in the 2750-3350 cm^{-1} region: 1) semicarbazone of aldehyde (III); 2) semicarbazone of β-methylcrotonaldehyde; 3) semicarbazone of the hydration product of aldehyde (III).

Comparison of the IR spectra of the semicarbazones of the ketoaldehyde $C_{10}H_{14}O_2$ and compounds of known structure confirms that the mutual disposition of carbonyl groups in the substance being studied is correctly expressed by Formula (IV) or (V), and also provides grounds for supposing that Formula (V) more accurately represents the position of the second double bond in the molecule.

In the 1500-1800 cm^{-1} region (Fig. 4), the compound under investigation has three intense absorption bands near 1710, 1665, and 1600 cm^{-1}. In contrast to the semicarbazone of the original acetylenic compound (III), the spectrum of the substance being studied contains the band of the free carbonyl group at 1665 cm^{-1}, displaced toward the longwave region, owing to conjugation with multiple bonds. The spectra of semicarbazones (XII) and (XIV) contain similar bands (1665-1660 cm^{-1}). The band in the 1700 cm^{-1} region is characteristic of all compounds compared, and may belong to the carbonyl group of the semicarbazide radical, whereas the band in the 1600 cm^{-1} region may characterize vibrations of the conjugated double bonds. There is no band in the spectrum, which could characterize an isolated double bond at the end of the chain, while the spectrum of pseudoionone, which contains the isolated double bond $-C=C(CH_3)_2$, has a well-defined band at 1635 cm^{-1} [15]. These data are in accord with the structure of the substance, shown in Formula (V). Further evidence in favor of Formula (V) consists in the fact that in the region of C−H bond vibrations (Fig. 5), in the spectrum of the semicarbazone of the compound being studied, the 3012 cm^{-1} band, which usually characterizes the −CH=C< group [18], is absent. On the contrary, the 3012 cm^{-1} band is well marked in the spectra of compounds having this group − 3,7-dimethyl-octadien-2,6-yn-4-al (III) and β-methylcrotonaldehyde (Fig. 5).

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EXPERIMENTAL

1. 1,6-Dihydroxy-3,7-Dimethylocten-2-Yne-4 (VIII, R = H)

The ethylmagnesium bromide solution prepared from 17.5 g of magnesium and 79.5 g of ethyl bromide in 130 ml of ether was cooled to 10°, 34.94 g of 1-hydroxy-3-methylpentenyne (VII) in 40 ml of dry ether was added with stirring, and the mixture was refluxed for 30 min. The magnesium complex formed was cooled to 10-15°, 24.2 g of isobutyraldehyde (freshly distilled, b.p. 63-64°) in 30 ml of ether was added dropwise, and the mixture was stirred for 2 hr at room temperature and left overnight. The reaction mass was poured into a mixture of 200 g of ice and 50 ml of 10% sulfuric acid. The organic layer was drawn off and the water layer further extracted with ether. The combined ether extracts were washed with saturated sodium bicarbonate solution and dried with magnesium sulfate. The solvent was evaporated and the residue distilled. Yield of 1,6-dihydroxy-3,7-dimethyl-octen-2-yne-4, 35.1 g (62%).

B.p. 112-114° (0.3 mm), d^{20}_4 0.9887, $n^{20}D$ 1.4987, MR_D 48.93; calc. 48.96.

Found %: C 71.11; H 9.60. H_{act} 1.1. $C_{10}H_{16}O_2$.

Calculated %: C 71.44; H 9.53. H_{act} 1.19.

2. 1-Acetoxy-6-Hydroxy-3,7-Dimethylocten-2-Yne-4 (VIII, R = COCH₃)

19 g of (VIII, R = H) was dissolved in 57 ml of anhydrous benzene and 19 ml of pyridine, the solution cooled to −3°, and 8.87 g of acetyl chloride in 16 ml of benzene added dropwise. The mixture was stirred for 1 hr at 0° and left overnight. The reaction mass was poured into a mixture of 140 ml of ice water and 15 ml of 10% sulfuric acid, and the benzene layer was drawn off, washed with saturated sodium bicarbonate solution, and dried with potash. The benzene was evaporated and the residue distilled. Yield 20.51 g (86.5%).

B.p. 110-112° (1 mm), d^{20}_4 1.0016, $n^{20}D$ 1.4801, MR_D 58.72; calc. 58.32.

Found %: C 68.26; H 8.49. H_{act} 0.47. $C_{12}H_{18}O_3$.

Calculated %: C 68.58; H 8.57. H_{act} 0.48.

3. 3,7-Dimethyloctadien-2,6-Yn-4-Al (III).

To a mixture, heated to boiling, of 10.52 ml of phosphorus oxychloride, 48 ml of anhydrous benzene, and 48 ml of pyridine,was added 20 g of 1-acetoxy-6-hydroxy-3,7-dimethylocten-2-yne-4 (VIII, R = COCH₃) in 48 ml of benzene with stirring, and heating was continued for 3 hr. The reaction mass was cooled and poured into a mixture of 100 ml of water, 100 g of ice, and 20 ml of 10% sulfuric acid, the benzene layer drawn off, and the water layer further extracted with ether. The combined extracts were washed with 5% sulfuric acid and bicarbonate solutions and dried with magnesium sulfate. The solvent was evaporated, and the residue was distilled under reduced pressure. Yield of 1-acetoxy-3,7-dimethyloctadien-2,6-yne-4 (IX, R = COCH₃), 10.91 g (59.9%).

B.p. 90-103° (1 mm), $n^{20}D$ 1.4975; λ_{max} 270, 230 mµ, $E^{1\%}_{1cm}$ 519, 387.

Simultaneously, a second substance (2.95 g) with b.p. 103-112° (1 mm), $n^{20}D$ 1.4850, was obtained, which was not further investigated.

Alkaline hydrolysis of 1-acetoxy-3,7-dimethyloctadiene-2,6-yne-4 (IX, R = COCH₃). A 7.3 g quantity of (IX, R = COCH₃) was dissolved in 36.5 ml of 1 N methanolic potassium hydroxide, and the mixture was refluxed for 1 hr and poured into 150 ml of water; extraction with ether followed, and the 1-hydroxy-3,7-dimethyloctadien--2,6-yne-4 (IX, R = H) obtained was distilled. Yield 4.11 g (72%).

B.p. 94-108° (1 mm), $n^{20}D$ 1.5211.

Microhydrogenation. 41.6 mg of the substance absorbed 30.0 ml of H_2 (22°, 741.7 mm). Calculated, 29.33 ml of H_2.

Oxidation of 1-hydroxy-3,7-dimethyloctadien-2,6-yne-4 (IX, R = H). A 3.2 g quantity of (IX, R = H) was dissolved in 150 ml of petroleum ether (b.p. 80-90°) which was then added to 32 g of activated manganese di-oxide; the mixture was shaken for 3 hr and filtered, the manganese dioxide washed with petroleum ether, and the

solvent evaporated. The 3,7-dimethyloctadien-2,6-yn-4-al obtained was distilled. Yield 2.34 g (74.1%). B.p. 70-74° (1 mm), $n^{20}D$ 1.5362.

Semicarbazone. Four-tenths g of semicarbazide hydrochloride in 1.2 ml of water was mixed with a solution of 0.4 g of potassium acetate in 0.8 ml of alcohol and added to a solution of 0.62 g of the aldehyde in 1.2 ml of alcohol. After standing for 14 hr in the cold, the mixture was filtered. The 3,7-dimethyloctadien-2,6-yn-4--al (III) semicarbazone was recrystallized from alcohol.

M.p. 182-183°, λ_{max} 315, 240 mμ, $E_{1cm}^{1\%}$ 1350, 500 (respectively).

Found %: C 64.53; H 7.21; N 20.45. $C_{11}H_{15}ON_3$.

Calculated %: C 64.39; H 7.32; N 20.48.

4. 3,7-Dimethyloctadien-2,5-on-4-al (V)

A 0.76 g quantity of 3,7-dimethyloctadien-2,6-yn-4-al (III) was dissolved in 2.5 ml of 80% methanol and 0.0274 g of mercuric sulfate added. The mixture was heated for 1 hr and 45 min at 65-67° with vigorous stirring. The reaction mass became quite dark. It was cooled, poured into 50 ml of cold water, neutralized with dry sodium bicarbonate, extracted with ether, and the extract dried with magnesium sulfate. The solvent was evaporated and the residue distilled. The fraction boiling in the range 69-75° (1 mm) was collected. Yield 0.53 g (62.1%). A light-yellow, mobile liquid, $n^{20}D$ 1.5157; does not give a coloration with alcoholic ferric chloride solution.

Semicarbazone. A solution of 0.45 g of semicarbazide hydrochloride in 1 ml of water was mixed with one of 0.36 g of potassium acetate in 0.72 ml of ethanol, and added to one of 0.53 g of the substance in 1 ml of ethanol. Crystallization began on standing. Yield 0.61 g (85.5%).

M.p. 152-153° (from alcohol), λ_{max} 308, 235 mμ, $E_{1cm}^{1\%}$ 1580, 495 (respectively).

Found %: C 59.09; H 7.63; N 18.70. $C_{11}H_{17}O_2N_3$.

Calculated %: C 59.20; H 7.66; N 18.87.

5. 1-Acetoxy-3-methylpenten-2-yne-4 (VIIa)

20 g of 1-hydroxy-3-methylpenten-2-yne-4 (VII) was dissolved in 60 ml of anhydrous benzene and 20 ml of pyridine, the solution cooled to −2°, and 17.2 g of acetyl chloride in 30 ml of benzene added dropwise. The mixture was stirred for 1 hr at 0° and left overnight. The reaction mass was poured into a mixture of 140 ml of ice water and 15 ml of 10% sulfuric acid, and the benzene layer was drawn off, washed with saturated sodium bicarbonate solution, and dried with magnesium sulfate. The benzene was evaporated and the residue distilled. Yield 23.75 g (82.4%). Colorless, mobile liquid with a characteristic ethereal odor.

B.p. 93-94° (20 mm), d^{20}_4 0.9828, $n^{20}D$ 1.4623, MR_D 38.61; calc. 38.33.

Found %: C 69.69; H 7.10. $C_8H_{10}O_2$.

Calculated %: C 69.95; H 7.25.

6. 1-Acetoxy-3-methylpenten-2-one-4 (X)

To a suspension of 0.443 g of mercuric sulfate in 66 ml of 90% acetic acid (d 1.0661), heated to 85-87°, a solution of 12.78 g of 1-acetoxy-3-methylpenten-2-yne-4 in 13 ml of 90% acetic acid was added dropwise during 20 min. The mixture was heated at 85-87° for 5 hours with vigorous stirring. The acetic acid was distilled off under reduced pressure (10 mm) at a bath temperature not over 35-40°. The residue was poured into 100 ml of water and neutralized with solid sodium bicarbonate. Extraction with ether followed, and the extract was dried with magnesium sulfate. The solvent was evaporated at reduced pressure. The residue was distilled. Yield 6.91 g (52.3%).

B.p. 75-76° (4 mm), d^{20}_4 1.060, $n^{20}D$ 1.4656, MR_D 40.80; calc. 40.34.

Found %: C 61.35; H 7.67. $C_8H_{12}O_3$.

Calculated %: C 61.55; H 7.69.

Semicarbazone: m.p. 167-168° (from ethanol); λ_{max} 261 mμ, $E_{1cm}^{1\%}$ 1230.

Found %: N 19.59. $C_9H_{15}O_3N_3$.

Calculated %: N 19.72.

7. 1-Hydroxy-3-methylpenten-2-one-4 (Xa)

To 2 g of (X) in 4 ml of methanol was added 8 ml of methanol saturated with ammonia (at 0°). The reaction mass was left overnight at −2°. The alcohol was evaporated under reduced pressure at a bath temperature not over 30° and the residue distilled. Yield 0.97 g (66.5%). B.p. 103-107° (2 mm) n_D^{20} 1.4837.

Semicarbazone (XIII): m.p. 172-173° (from ethanol); λ_{max} 261 mμ, $E_{1cm}^{1\%}$ 1310.

Found %: C 49.15; H 7.58; N 24.59. $C_7H_{13}O_2N_3$.

Calculated %: C 49.12; H 7.66; N 24.56.

8. 3-Methylpenten-2-on-4-al (XI)

A 0.93 g quantity of (X) was dissolved in 76 ml of dry acetone, 9.3 g of manganese dioxide added, and the mixture shaken for 4 hr. The manganese dioxide was filtered out and washed several times with acetone in the filter. The solvent was evaporated at reduced pressure, and the residue distilled. Yield 4.42 g (48.2%). B.p. 80-83° (2 mm), n_D^{20} 1.4813.

Semicarbazone (XII): m.p. 197-198°, λ_{max} 307 mμ, $E_{1cm}^{1\%}$ 1516.

Found %: C 49.84; H 6.71; N 24.91. $C_7H_{11}O_2N_3$.

Calculated %: C 49.71; H 6.509; N 24.85.

Semicarbazone (XIV). A 1.22 g quantity of semicarbazone (XIII) (m.p. 172-173°) was dissolved in 475 ml of dry acetone, added to 12 g of activated manganese dioxide, and shaken for 3 hr. The mixture was filtered, the manganese dioxide washed with warm acetone, the solvent evaporated, and the solid residue recrystallized from ethanol. Yield 0.85 g (70.6%). M.p. 167-167.5°, λ_{max} 306 mμ, $E_{1cm}^{1\%}$ 1365.

Found %: C 49.86; H 6.69; N 24.75. $C_7H_{11}O_2N_3$.

Calculated %: C 49.71; H 6.51; N 24.85.

SUMMARY

It has been shown that on hydration of the triple bond in the 3,7-dimethyloctadien-2,6-yn-4-al molecule, which contains a dienyne system conjugated with a carbonyl group, 3,7-dimethyloctadien-2,5-on-4-al is formed; the latter is distinguished by the conjugation of all the multiple bonds contained in it.

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SYNTHESIS OF SUBSTITUTED 7-AMINOMETHYL-6-(β-AMINOETHYL)-
-1-AZABICYCLO-(3,2,1)-OCTANES

V. Ya. Furshtatova, E. E. Mikhlina and M. V. Rubtsov

S. Ordzhonikidze All-Union Chemical-Pharmaceutical Scientific Research Institute

Original article submitted May 15, 1958

In one of the preceding articles [1], we described the synthesis of 6-carboxymethyl-1-azabicyclo-(3,2,1)-
-octane-7-carboxylic acid and some of its derivatives. The presence of two carboxyl groups in the stated acid
made it possible to synthesize a series of substituted 7-aminomethyl-6-(β-aminoethyl)-1-azabicyclo-(3,2,1)-
-octanes and to study their biological properties. Our interest in such compounds was due to the fact that certain
2,3-disubstituted derivatives of an isomeric bicyclic system — quinuclidine — exhibited high pharmacological
activity [2,3].

In order to prepare 6,7-diamino-substituted 1-azabicyclo-(3,2,1)-octanes, 6-carboxymethyl-1-azabicyclo-
-(3,2,1)-octane-7-carboxylic acid hydrochloride (I) was converted by means of thionyl chloride to the correspond-
ing acid chloride (II). On treatment of the latter with alkyl (aryl) amines, the corresponding amides (III) were
obtained. Reduction of the amides with lithium aluminum hydride led to substituted 7-aminomethyl-6-(β-
-aminoethyl)-1-azabicyclo-(3,2,1)-octanes (IV):

(IIIa) & (IVa) $R_1 = R = C_2H_5$,
(IIIb) & (IVb) $R_1 = R = CH_3$,
(IIIc) & (IVc) $R = CH_2C_6H_5$,
$R_1 = H$.
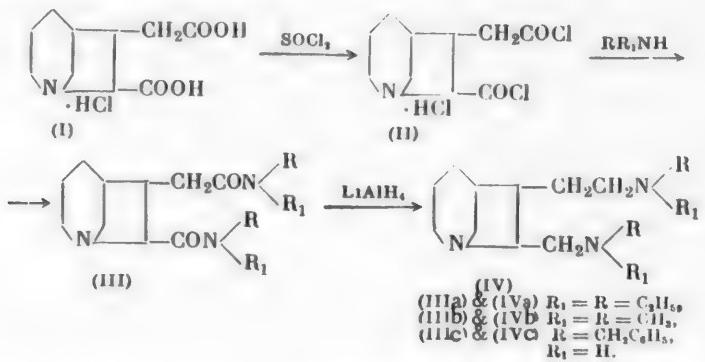
On studying the properties of the synthesized diamines (IV) it was found that diamines having an unsubsti-
tuted hydrogen atom on the nitrogen are converted on distillation in vacuo to a tricyclic system — 6,7-(3',4'-N-
-alkylpiperidino)-1-azabicyclo-(3,2,1)-octane (V).

(IVc) $R = CH_2C_6H_5$,
(IVd) $R = CH_2CH_2N(C_2H_5)_2$,

(Va) $R = CH_2C_6H_5$,
(Vb) $R = CH_2CH_2N(C_2H_5)_2$.
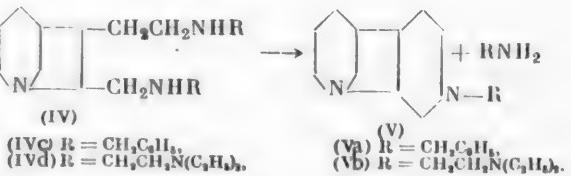
The formation of tricyclic system (V) on distillation of diamines (IV) was confirmed by the countersynthesis of 6,7-(3',4'-N-benzylpiperidino)-1-azabicyclo-(3,2,1)-octane (Va) according to the scheme:
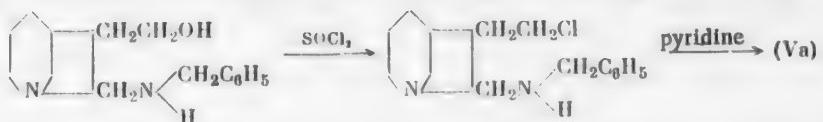
7-Benzylaminomethyl-6-(β-hydroxyethyl)-1-azabicyclo-(3,2,1)-octane [4] was converted by means of thionyl chloride to 7-benzylaminomethyl-6-(β-chloroethyl)-1-azabicyclo-(3,2,1)-octane. The latter, on boiling in pyridine, gave 6,7-(3',4'-N-benzylpiperidino)-1-azabicyclo-(3,2,1)-octane (Va).

EXPERIMENTAL

6-Carboxymethyl-1-azabicyclo-(3,2,1)-octane-7-carboxylic acid di-(diethylamide) (IIIa). 3 g of 6-carboxymethyl-1-azabicyclo-(3,2,1)-octane-7-carboxylic acid hydrochloride (I) was heated with 30 ml of thionyl chloride for 6 hr at 60-65°. The excess of thionyl chloride was distilled off in vacuo; the last traces of it were removed by twice adding benzene, and subsequently distilling it off. The frothy mass, which consisted of the acid chloride hydrochloride (II), was treated, with cooling, with a solution of 8.8 g of diethylamine in 20 ml of dry ether. The reaction mixture was left standing for 30 min. Then 20 ml of 50% potash solution was added and the separated oil extracted with ether. The ethereal solution was dried with potash. After driving off the solvent in vacuo, the residue was distilled. B.p. 170-190° (0.5 mm). There was obtained 2.7 g (69.5%) of 6-carboxymethyl-1-azabicyclo-(3,2,1)-octane-7-carboxylic acid di-(diethylamide), which was a yellow oil, soluble in organic solvents and water.

Picrate: yellow crystals, soluble in alcohol and acetone and insoluble in water and ether. M.p. 151-152° (from alcohol).

Found %: C 52.37; H 6.88; N 15.34. $C_{24}H_{36}O_9N_6$.

Calculated %: C 52.17; H 6.52; N 15.33.

6-Carboxymethyl-1-azabicyclo-(3,2,1)-octane-7-carboxylic acid di-(dimethylamide) (IIIb). The acid chloride hydrochloride obtained from 3 g of 6-carboxymethyl-1-azabicyclo-(3,2,1)-octane-7-carboxylic acid was treated with 25 ml of a 39% ethereal solution of dimethylamine. After treatment similar to that described for the synthesis of IIIa, there was obtained 2.25 g (70.5% of 6-carboxymethyl-1-azabicyclo-(3,2,1)-octane-7--carboxylic acid di-(dimethylamide). A viscous, yellow liquid, readily soluble in water and organic solvents.

Found %: C 62.75; H 9.54. $C_{14}H_{25}O_2N_3$.

Calculated %: C 62.92; H 9.36.

6-Carboxymethyl-1-azabicyclo-(3,2,1)-octane-7-carboxylic acid dibenzylamide (IIIc). A mixture of 2.5 g of ethyl 6-carbethoxymethyl-1-azabicyclo-(3,2,1)-octane-7-carboxylate [3] and 25 ml of benzylamine was refluxed for 60 hr. The excess benzylamine was driven off in vacuo and the residue distilled. B.p. 250° (0.35 mm). There was obtained 3.44 g (95%) of 6-carboxymethyl-1-azabicyclo-(3,2,1)-octane-7-carboxylic acid dibenzylamide in the form of a vitreous mass which hardened on trituration with ether. The substance was an amorphous, yellow powder, soluble in chloroform, alcohol, and water, and insoluble in ether. M.p. 52-60°.

Found %: N 10.50, 10.66. $C_{24}H_{29}O_2N_3$.

Calculated %: N 10.73.

7-Diethylaminomethyl-6-(β-diethylaminoethyl)-1-azabicyclo-(3,2,1)-octane (IVa). To a suspension of 1.42 g of lithium aluminum hydride in 40 ml of dry ether, a solution of 3 g of the amide (IIIa) in 40 ml of benzene was added with stirring. The reaction mass was refluxed for 20 hr. Then 2.8 ml of water was added with cooling and stirring, and the lithium and aluminum hydroxides were filtered out and well washed with ether. The extracts were dried with potash. After the solvent was driven off, the residue was distilled in vacuo. There was obtained 2.53 g (93%) of 7-diethylaminomethyl-6-diethylaminoethyl-1-azabicyclo-(3,2,1)-octane in the form of a colorless, mobile liquid, readily soluble in water and organic solvents. B.p. 124-125° (0.2 mm), $n^{17}D$ 1.485.

Found %: N 14.08, 14.38. $C_{18}H_{37}N_3$.

Calculated %: N 14.24.

7-Dimethylaminomethyl-6-(β-dimethylaminoethyl)-1-azabicyclo-(3,2,1)-octane (IVb). A solution of 2.25 g of amide (IIIb) in 30 ml of benzene was added to a suspension of 1.5 g of lithium aluminum hydride in 20 ml of ether. After heating for 20 hr the reaction mass was treated as in the preceding experiment. There was obtained 1.26 g (62.5%) of the substance, which was a colorless, mobile liquid, readily soluble in water and organic solvents.

Found %: N 17.66, 17.37. $C_{14}H_{29}N_3$.

Calculated %: N 17.58.

7-Benzylaminomethyl-6-(β-benzylaminoethyl)-1-azabicyclo-(3,2,1)-octane (IVc). To a solution of 0.62 g of lithium aluminum hydride in 20 ml of dibutyl ether was added 2.2 g of amide (IIIc). The mixture was refluxed for 20 hr and further treated as described above. After the solvent was distilled off, there was obtained 1.9 g (93%) of 7-benzylaminomethyl-6-(β-benzylaminoethyl)-1-azabicyclo-(3,2,1)-octane, which was a viscous, yellow liquid, soluble in organic solvents and water.

Found: M 360. $C_{24}H_{33}N_3$.

Calculated: M 363.

Dipicrate: yellow crystals, soluble in water, acetone, and alcohol, and insoluble in ether. M.p. 97°.

Found %: C 48.5; H 4.29; N 15.78. $C_{36}H_{39}O_{14}N_9$.

Calculated %: C 48.00; H 4.00; N 16.00.

6,7-(3',4'-N-Benzylpiperidino)-1-azabicyclo-(3,2,1)-octane (Va). a) A 1.9 g quantity of 7-benzylamino-methyl-6-(β-benzylaminoethyl)-1-azabicyclo-(3,2,1)-octane was distilled in vacuo. B.p. 210-240° (0.3 mm). There was obtained 1.2 g (90%) of 6,7-(3',4'-N-benzylpiperidino)-1-azabicyclo-(3,2,1)-octane. A viscous, yellow oil, soluble in organic solvents and water.

Found: M 258. $C_{17}H_{24}N_2$.

Calculated: M 256.

Dipicrate: yellow crystals, soluble in alcohol and acetone, and insoluble in water and ether. M.p. 118°.

Found %: C 49.04, 48.7; H 4.5, 4.3; N 15.33, 15.41. $C_{29}H_{30}O_{14}N_8$.

Calculated %: C 48.7; H 4.2; N 15.66.

b) To the 7-benzylaminomethyl-6-(β-hydroxyethyl)-1-azabicyclo-(3,2,1)-octane hydrochloride obtained from 2.2 g of the base, was added 20 ml of dry chloroform; 20 ml of thionyl chloride was then gradually added with cooling. The reaction mass was refluxed for 2 hours. The chloroform and excess thionyl chloride were removed in vacuo, and the residue was treated with 50% potash solution, and the 7-benzylaminomethyl-6-(β-chloro-ethyl)-1-azabicyclo-(3,2,1)-octane extracted with chloroform. After the chloroform was distilled off in vacuo, the chloride obtained was dissolved in 20 ml of pyridine and the solution boiled for 2 hr. Then the pyridine was distilled off and the residue was treated with 50% potash solution and extracted with ether. The ethereal solution was dried with potash and evaporated in vacuo, and the substance was distilled. There was obtained 1.3 g of 6,7-(3',4'-N-benzylpiperidino)-1-azabicyclo-(3,2,1)-octane. B.p. 218° (0.3 mm).

Dipicrate: yellow crystals, soluble in alcohol and acetone, and insoluble in water and ether. M.p. 118°.

Found %: N 16.08. $C_{29}H_{30}O_{14}N_8$.

Calculated %: N 15.66.

The 6,7-(3',4'-N-benzylpiperidino)-1-azabicyclo-(3,2,1)-octane dipicrate obtained proved to be identical (no melting-point depression on melting of mixed dipicrate samples) with the dipicrate of the substance formed on distillation of 7-benzylaminomethyl-6-(β-benzylaminoethyl)-1-azabicyclo-(3,2,1)-octane.

6,7-(3',4'-N-Diethylaminoethylpiperidino)-1-azabicyclo-(3,2,1)-octane (Vb). The acid chloride hydrochloride obtained from 2 g of 6-carboxymethyl-1-azabicyclo-(3,2,1)-octane-7-carboxylic acid was suspended in 25 ml of dry ether and the suspension added to a solution of 5 g of diethylaminoethylamine in 25 ml of benzene, with good cooling and stirring. After treatment corresponding to that described for the synthesis of (IIIa), there was obtained 2.5 g (76.5%) of 6-carboxymethyl-1-azabicyclo-(3,2,1)-octane-7-carboxylic acid di-(diethylaminoethylamide) in the form of a brown oil, easily decomposed on distillation. For this reason, the amide obtained was reduced by lithium aluminum hydride without purification; 1 g of the amide was treated with 1 g of lithium aluminum hydride in a mixture of 30 ml of benzene and 30 ml of ether, and the reaction mass refluxed for 20 hr. The latter was then decomposed by water and extracted with chloroform. The chloroform solution was dried with potash. After removal of the chloroform, there remained 2 g (85.5%) of 7-diethylaminoethylaminomethyl-6-(β--diethylaminoethylaminoethyl)-1-azabicyclo-(3,2,1)-octane in the form of an immobile, brown oil, soluble in organic solvents and water. The diamine obtained was distilled in vacuo; in this case, there was formed 1.2 g (86%) of 6,7-(3',4'-N-diethylaminoethylpiperidino)-1-azabicyclo-(3,2,1)-octane in the form of a viscous, yellow oil, soluble in organic solvents and water. B.p. 200-210° (0.3 mm).

Found %: M 268. $C_{16}H_{31}N_3$.

Calculated %: M 265.

Tripicrate: yellow crystals, soluble in alcohol and acetone, and insoluble in ether. M.p. 120°.

Found %: C 42.22, 42.24; H 4.38, 4.53; N 17.68, 17.31. $C_{34}H_{40}O_{21}N_{12}$.

Calculated %: C 42.62; H 4.17; N 17.62.

SUMMARY

A series of disubstituted 7-aminomethyl-6-(β-aminoethyl)-1-azabicyclo-(3,2,1)-octanes have been synthesized proceeding from 6-carboxymethyl-1-azabicyclo-(3,2,1)-octane-7-carboxylic acid.

Distillation in vacuo of amines having an unsubstituted hydrogen atom on each of the nitrogens is accompanied by splitting-off of one alkylamine molecule and formation of the tricyclic system 6,7-(3',4'-N-alkylpiperidino)-1-azabicyclo-(3,2,1)-octane.

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SYNTHESIS OF 9,10-DIALKYLLILOLIDENES

A. N. Kost, L. G. Yudin and A. N. Terent'ev

Moscow State University

Original article submitted April 14, 1958

Among the compounds of the indole series, substances, having the structure of indole nonlinearly condensed with other rings have been studied relatively little. In particular, compounds with rings fused in positions 1 and 7 have scarcely been investigated.

In 1918, Braun [1], by the reaction of trimethylene chlorobromide with indoline, obtained a tricyclic substance (I), which he called lilolidine by analogy with yulolidine. This system is listed under this name in Patterson's Ring Index [2], albeit with a very arbitrary numeration of atoms. According to the rules of systematic nomenclature [3], this structure should be numbered as indicated in the present article, and named "8-azatricyclo-[11, 12(4, 8)]-dodecarene-1." In view of the unwieldiness of this name, we shall use the term suggested by Braun, but we shall employ the systematic numeration of atoms.
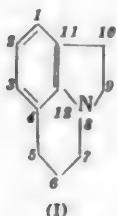
Besides the synthesis mentioned above, a method of preparation of lilolidine systems, based on the Fischer reaction, has been proposed [4]. Namely, from 1,2,3,4-tetrahydroquinoline through the nitroso compound (II) there was obtained 1-aminotetrahydroquinoline (III), which, on reaction with pyruvic acid, gave a hydrazone; the latter was converted by heating with zinc chloride to lilolidenecarboxylic acid. The structure of the latter was confirmed by decarboxylation and reduction to lilolidine (I).

We used this method for the synthesis of a series of 9,10-dialkyllilolidenes-9 according to the general scheme:
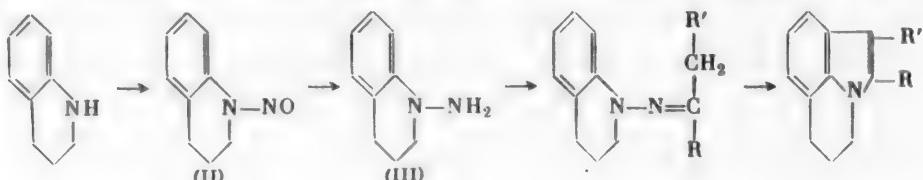
We nitrosated tetrahydroquinoline in dilute sulfuric acid because of the possibility of migration of the nitroso group to position 6 when this reaction is carried out in hydrochloric acid, or when hydrochloric acid is added to nitrosotetrahydroquinoline [5]. The precipitated nitroso compound was extracted with ether, the extract being washed several times with water since, according to our observations, nitroso compound (II), containing traces of nitric or nitrous acid, gives low yields of 1-aminotetrahydroquinoline.

The method, described in the literature [4,6] of reduction of nitrosotetrahydroquinoline by heating in a water bath with alcohol, zinc, and acetic acid, gives low yields of amine (III). The fact is that, under these relatively severe conditions, the nitroso group is partially eliminated, and the main reaction product proves to be tetrahydroquinoline. In connection with this, after a number of experiments, we carried out the reduction at a temperature of 10-15°, using methyl alcohol instead of ethyl. In this case, the yields of amine (III) rose to 75-80%, reckoned on the original tetrahydroquinoline. When the 1-aminotetrahydroquinoline obtained in this way is heated in a
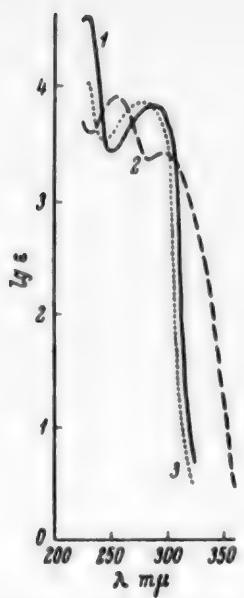
Absorption spectra in the ultra-violet region: 1) 9,10-dimethyl-lilolidene-9 (IV); 2) 9,10-di-methyllilolidine (V); 3) 1-methyl-indole, λ_{max} 275 mμ, lg ϵ 3.75.

water bath with carbonyl-containing compounds, there are formed oily hydrazines, which we converted to lilolidenes without first isolating them in a pure state.

The usual reagent for the Fischer rearrangement — anhydrous zinc chloride — proved unsuitable since a considerable amount of tar was formed in its presence, and the substances obtained were difficult to purify. If the process is carried out with dilute sulfuric acid, lilolidenes are formed rapidly on mild heating, with yields of 60 to 95%, no tar formation being observed.

In order to confirm the structures of the substances obtained, we reduced 9,10-dimethyllilolidene-9 (IV) with zinc in hydrochloric acid and thus obtained 9,10-dimethyllilolidine (V), which was obtained also in the reaction of 2,3-dimethylindoline with trimethylene chloro-bromide.
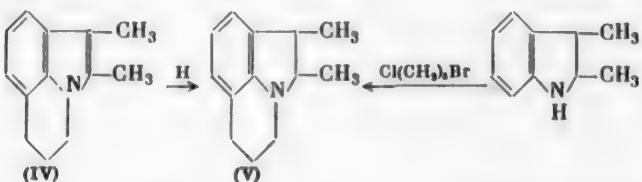
Besides mixed melting-point tests (which showed no depression), we proved the identity of these substances, obtained by different routes, by comparing the absorption spectra. All lilolidenes have similar absorption curves (see figure), analogous to the curve for 1-methylindole. In all cases, besides the maximum near 290 mμ, there is a second maximum in the 231-233 mμ region. For hydrogenated compound (V), these maxima are shifted to the right.

It should be noted that we synthesized lilolidenes, using as the second component such compounds as ethyl methyl ketone, diethyl ketone, butyl methyl ketone, phenylacetone, cyclohexanone, and 2-methylcyclohexanone. At the same time, we were unable to isolate individual substances on carrying out the reaction with acetone, which corresponds to literature data [4]. In the cases of cyclohexanone and 2-methylcyclohexanone, the substances formed have a tetracyclic structure (VI) and (VII). For this we used the name "pyrido[l,m-1,2,3]carbazole," following Patterson [2], but employed a systematic numeration of the atoms:

(VI) R = H; (VII) R = CH$_3$

Earlier, we published a short article [7] on part of the data of this work.

EXPERIMENTAL

1-Amino-1,2,3,4-tetrahydroquinoline. In 160 ml of 12% sulfuric acid was dissolved 26.6 g of 1,2,3,4-tetra-hydroquinoline [8], the solution was cooled (from 0 to −2°), and a saturated aqueous solution of 17 g of sodium nitrite was added, with stirring, at such a rate that the temperature of the mixture did not rise above 0° (external cooling). Then the cooling was stopped, and the reaction mass was left standing for 30 min, the separated oil extracted with ether, and the ethereal extract thoroughly (3-4 times) washed with water. After removal of the ether (in vacuo) the light-yellow, oily nitroso compound (II) remained in quantitative yield.

To a solution of 32 g of this nitroso compound (II) in 300 ml of methyl alcohol was added 80-100 g of zinc

dust, the mixture was cooled to 10°, and 100 ml of acetic acid was gradually added, with vigorous stirring, at such a rate that the temperature of the mixture did not rise above 14-15°. The mixture was stirred at 14-16° for 2-3 hr more and left overnight at room temperature. The excess zinc was filtered out and thoroughly washed with dilute hydrochloric acid and hot water. The wash waters were combined with the filtrate, which was evaporated in vacuo until the methanol was eliminated. The remaining aqueous solution was made strongly alkaline and extracted with ether. The extract was dried with fused alkali, the ether driven off, and the residue distilled in vacuo, the fraction with b.p. 120-125° (5 mm) being collected. The substance crystallized on standing. There was obtained 23.7 g (80%) of 1-amino-1,2,3,4-tetrahydroquinoline (III), m.p. 55° (from octane). According to cited data [6], b.p. 255°, m.p. 55-56°.

9,10-Dimethyllilolidene-9 (IV). A mixture of 3 g of amine (III) and a twofold excess of ethyl methyl ketone was refluxed for 3-4 hr in a water bath. The unreacted ketone was distilled off in vacuo, the residue heated to 70-80°, and 12 ml of hot 10-12% sulfuric acid added. The reaction mixture was heated in the water bath for 30-40 min and cooled, and the precipitate of 9,10-dimethyllilolidene-9 (IV) was filtered out; yield 2.9 g (80%), m.p. 87-88° (from alcohol), λ_{max} 232, 290 mμ, log ϵ 4.604, 3.845.

Found %: C 84.03, 84.20; H 8.10, 8.27; N 7.82, 7.89. $C_{13}H_{15}N$.

Calculated %: C 84.28; H 8.16; N 7.56.

Picrate: m.p. 154-155° (from alcohol).

Found %: C 54.79, 54.98; H 4.52, 4.58; N 13.15, 13.28. $C_{19}H_{18}O_7N_4$.

Calculated %: C 55.06; H 4.37; N 13.52.

9-Ethyl-10-methyllilolidene-9. A mixture of 3 g of amine (III) and a twofold excess of diethyl ketone was refluxed for 3.5-4 hours in a water bath, the excess ketone distilled off in vacuo, and the residue treated as in the preceding experiment. There was obtained 3.2 g (82%) of 9-ethyl-10-methyllilolidene-9, m.p. 39° (from alcohol), λ_{max} 233, 290 mμ, log ϵ 4.519, 3.897.

Found %: C 84.22, 84.24; H 8.72, 8.78; N 7.00, 7.03. $C_{14}H_{17}N$.

Calculated %: C 84.37; H 8.59; N 7.02.

9-Methyl-10-propyllilolidene-9. As in the preceding, 3 g of amine (III) and an excess of butyl methyl ketone (in a water bath for 2 hr), after treatment with sulfuric acid, gave 2.9 g (70%) of 9-methyl-10-propyllilolidene-9, m.p. 57-58° (from alcohol), λ_{max} 231, 290 mμ, log ϵ 4.42, 3.857.

Found %: N 6.71, 6.87. $C_{15}H_{19}N$.

Calculated %: N 6.56.

Picrate: m.p. 83° (from alcohol).

Found %: C 56.74, 56.96; H 5.07, 5.17. $C_{21}H_{22}O_7N_4$.

Calculated %: C 57.00; H 5.01.

9-Methyl-10-phenyllilolidene-9. As above, 1.5 g of amine (III) and phenylacetone, on heating in a water bath (4 hr) and subsequent treatment with 10% sulfuric acid (8 ml), gave 2.1 g (84%) of 9-methyl-10-phenyllilolidene-9, m.p. 128° (from alcohol), λ_{max} 232, 288 mμ, log ϵ 4.539, 4.24.

Found %: C 87.31, 87.10; H 6.97, 6.98; N 5.77, 5.83. $C_{18}H_{17}N$.

Calculated %: C 87.41; H 6.92; N 5.66.

1,2,3,4,6,7,8,9-Octahydropyrido[l,m-1,2,3]carbazole (VI). On heating 0.75 g of amine (III) with a 1.5-fold excess of cyclohexanone for 2 hr in a water bath, and working up in the usual manner, there was obtained 1.0 g (95%) of pyridocarbazole (VI), m.p. 65° (from alcohol), λ_{max} 232, 290 mμ, log ϵ 4.820, 3.963.

Found %: C 85.00, 85.25; H 8.14, 8.33. $C_{15}H_{17}N$.

Calculated %: C 85.26; H 8.11.

4-Methyl-1,2,3,4,6,7,8,9-octahydropyrido[l,m-1,2,3]carbazole (VII). Similarly, 1.5 g of amine (III) and the corresponding quantity of 2-methylcyclohexanone gave 1.3 g (60%) of methylpyridocarbazole (VII), m.p. 78° (from alcohol), λ_{max} 232, 290 mμ, log ϵ 4.630, 3.913.

Found %: N 6.31, 6.35. $C_{16}H_{19}N$.

Calculated %: N 6.21.

9,10-Dimethylliolidine (V). A mixture of 3.7 g of 9,10-dimethylliolidene-9 (IV), 50 ml of alcohol, 5 g of zinc dust, and 10 ml of concentrated hydrochloric acid was refluxed for 2 hr in a water bath, and then another 10 ml of hydrochloric acid and 5 g of zinc dust were added, after which heating was continued. This operation was repeated 6 times (at 2-hr intervals). After cooling, the excess zinc was filtered out and washed with a small amount of dilute hydrochloric acid. The filtrate and wash waters were evaporated in vacuo in order to remove the alcohol, and the residue was alkalized and three times extracted with ether. From this extract, after drying with fused alkali, driving off the ether, and vacuum distillation, 3 g of 9,10-dimethylliolidine (V) was obtained.

B.p. 89-92° (1 mm), $n^{20}D$ 1.5602, d^{20}_4 1.0131, MR_D 59.84. $C_{13}H_{17}N$; calc. 59.98; λ_{max} 253, 299 mμ, log ϵ 3.74, 3.30.

Picrate: m.p. 152° (from alcohol).

Found %: N 13.35, 13.36. $C_{19}H_{20}O_7N_4$.

Calculated %: N 13.45.

For countersynthesis of this substance, 14.6 g of 2,3-dimethylindoline and 88 g of trimethylene chlorobromide were refluxed for 20 hr in an oil bath (bath temperature 150-160°). After cooling, the mixture was diluted with 50 ml of 10% hydrochloric acid and the excess trimethylene chlorobromide removed by steam distillation. The residue in the distilling flask was alkalized and extracted with ether. The ether extract was dried with calcined magnesium sulfate, the ether driven off, and the residue distilled in vacuo. There was obtained 8 g (40%) of 9,10-dimethylliolidine (V).

B.p. 96-98° (2 mm), $n^{20}D$ 1.5606, d^{20}_4 1.0130, MR_D 59.83; calc. 59.98, λ_{max} 254, 299 mμ, log ϵ 3.83, 3.39.

Picrate: m.p. 151-152° (from alcohol). A mixed melting-point test with the picrate obtained in the preceding experiment gave no depression.

The absorption spectra for all substances were taken in methyl alcohol by means of an SF-4 spectrophotometer with an I. V. Obreimov oscillographic attachment.

SUMMARY

A number of condensed tri- and tetracyclic compounds of the type of liolidene and pyridocarbazole, containing the indole nucleus, were obtained, proceeding from 1,2,3,4-tetrahydroquinoline through 1-aminotetrahydroquinoline.

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* Original Russian pagination. See C.B. translation.

SYNTHESIS OF CERTAIN DERIVATIVES OF ALKADIYNECARBOXYLIC ACIDS ON THE BASIS OF DIACETYLENE

E. G. Popova, L. A. Shevyakova and M. Ya. Kraft

S. Ordzhonikidze All-Union Scientific Research Chemical-Pharmaceutical Institute

Original article submitted June 2, 1958

In the present work, acids are described, the carboxyl groups of which are located next to conjugated triple bonds. Compounds of such a structure drew attention on account of the fact that such groupings are structural elements of the molecules of certain polyacetylenic antibiotics, e.g., agrocibin* and others [1]. In order to obtain diyne compounds, we used the relatively little-investigated condensation of diacetylene with alkyl halides [2-5], which, however, is of interest in the study of routes of synthesis of certain diacetylene compounds.

1,4-Dichlorobutyne was converted on treatment with sodium in liquid ammonia, to diacetylene, which, owing to its instability and explosion hazard, was not isolated, but was condensed, in the form of the sodium derivative, with the corresponding alkyl halides. In this way, the condensation of 1,3-chlorobromopropane with butyldiacetylene and diacetylene, which is not described in the literature, was carried out; in the latter case, the monosubstituted derivative was formed.

The diacetylenic hydrocarbons obtained are mobile liquids with a characteristic odor, unstable at room temperature, darkening in the light, but more stable in the form of ethereal solutions in the cold and in the dark.

Butyl- and 1-chloropropyldiacetylene were converted to octa-5,7-diyne-8-carboxylic and 1-chlorohepta--4,6-diyne-7-carboxylic acids, respectively, through carboxylation with solid carbon dioxide of the magnesium-bromide derivatives obtained by treatment of the above-mentioned hydrocarbons with ethylmagnesium bromide. On prolonged standing of methanolic solutions of these acids in the presence of sulfuric acid, their methyl esters were obtained; the latter were used, without purification, for preparation of the amides. 1-Chlorohepta-4,6-diyne--7-carboxylic acid was characterized by the isopropylamide and octa-5,7-diyne-8-carboxylic acid by the cupric salt, amide, and isopropylamide. The UV absorption spectra**of the latter two were investigated.

The alkadiynecarboxylic acid derivatives obtained were examined biologically.*** The isopropylamide and cupric salt of octa-5,7-diyne-8-carboxylic acid have bacteriostatic activity with respect to acid-resistant bacteria; the cupric salt is also active with respect to the diphtheria bacillus.

EXPERIMENTAL

<u>1,4-Dichlorobutyne</u> was prepared from 1,4-butynediol by the cited method [6], b.p. 64° (14 mm).

Sodium amide suspension was prepared according to the cited description [7].

<u>Butyldiacetylene</u> was prepared by the cited method [3], yield 47.6%, b.p. 68-68.5° (47 mm), according to literature data [7], b.p. 49° (47 mm).

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* Unidentified — Publisher's note.

** The UV absorption spectra were taken by Yu. N. Sheinker.

*** The examination was conducted by S. N. Milovanova and A. L. Mikerina.

Found %: C 90.48, 90.59; H 9.41, 9.43; HC≡C 23.74. C_8H_{10}.

Calculated %: C 90.56; H 9.44; HC≡C 23.58.

1-Chlorohepta-4,6-diyne. To a suspension of sodium amide in liquid ammonia, prepared from 12.93 g of sodium in the presence of 0.25 g of ferric nitrate, was added 23.21 g of 1,4-dichlorobutyne during 1 hr, followed by 30 g of 1,3-chlorobromopropane during 1 hr. At the end of the addition, stirring was continued for 4 hr and the mixture left overnight. The ammonia was evaporated. The residue obtained was shaken several times with ether. The solvent was removed, and the residue distilled in vacuo in a current of nitrogen. B.p. 52-53° (4 mm), yield 3.03 g (12.7%).

Found %: C 66.02, 66.95; H 5.85, 5.91. C_7H_7Cl.

Calculated %: C 66.42; H 5.57.

1-Chloroundeca-4,6-diyne. To a suspension of sodium amide in liquid ammonia, prepared from 5.34 g of sodium in the presence of 0.1 g of ferric nitrate, was added 24.6 g of butyldiacetylene during 30 min; at the end of the addition, the mixture was stirred for 1 hr, after which 36.54 g of 1,3-chlorobromopropane was added during 1 hr and the mixture then stirred for 12 more hours. The ammonia was evaporated, and the residue obtained was shaken several times with ether. The solvent was removed, and the residue distilled in vacuo. B.p. 76° (0.1 mm), yield 12.26 g (28.7%).

Found %: C 73.00, 72.80; H 8.28, 7.90. $C_{11}H_{15}Cl$.

Calculated %: C 72.32; H 8.27.

Cupric salt of octa-5,7-diyne-8-carboxylic acid. To an ice-cooled ethereal solution of ethylmagnesium bromide, obtained from 5.65 g of ethyl bromide and 1.25 g of magnesium, was added 5.5 g of butyldiacetylene during 40 min with stirring; the mixture was boiled for 1 hr, cooled to −50°, poured into an excess of solid carbon dioxide in ether, and left overnight. The ethereal solution was poured off, and 10 ml of 5 N hydrochloric acid was added to the oily residue. The oil layer was drawn off, and a little water was added to it, followed by powdered sodium bicarbonate, until foaming ceased. A solution of 8 g of $CuSO_4 \cdot 5H_2O$ in 24 ml of water was added to the water layer. The substance which crystallized on cooling was filtered out and washed with petroleum ether and then benzene.

A greenish-blue, crystalline substance which gradually decomposes on heating, and is readily soluble in alcohol and ether.

Found %: C 57.06, 57.40; H 5.29, 4.99; Cu 16.92, 16.49. $C_{18}H_{18}O_4Cu \cdot H_2O$.

Calculated %: C 56.91; H 5.31; Cu 16.73.

Octa-5,7-diyne-8-carboxylic acid amide. To 2.4 g of the cupric salt of octa-5,7-diyne-8-carboxylic acid was added 2.5 ml of 5 N hydrochloric acid, and the mixture was extracted several times with petroleum ether. The solvent was removed in vacuo, a solution of 2 ml of concentrated sulfuric acid in 66 ml of anhydrous methanol was added to the residue, and the resulting mixture was left for 5 days at 5°. To an ethereal solution of the crude methyl ester, obtained after the usual treatment, 0.7 ml of 35% aqueous ammonia solution was added, and the ice-cooled mixture was stirred for 50 hours. Then the solvent was removed, and the crystalline residue obtained thereby was washed with petroleum ether and recrystallized from carbon tetrachloride. A colorless, crystalline substance, m.p. 118°.

λ_{max} (in alcohol) 275, 260, 246, 233 mμ, (log ε 3.60, 3.76, 3.70, 3.68).

Found %: N 9.53. $C_9H_{11}ON$.

Calculated %: N 9.39.

Octa-5,7-diyne-8-carboxylic acid isopropylamide. To the crude methyl octa-5,7-diyne-8-carboxylate obtained as described above from 2.4 g of the cupric salt, was added 1.03 g of isopropylamine, and the mixture was left at +5° for 5 days. It was then washed with dilute hydrochloric acid and water, and extracted with ether. The solvent was removed, and the oily residue obtained was dissolved in a mixture of petroleum ether and benzene (4:1) and filtered through aluminum oxide. The solvent was distilled off in vacuo, and the residue obtained was recrystallized from the same mixture. A colorless, crystalline substance, m.p. 69°.

λ_{max} (in alcohol) 276, 260, 248, 236 mμ ,(log ϵ 3.77, 3.92, 3.90, 3.87).

Found %: N 7.48. $C_{11}H_{17}ON$.

Calculated %: N 7.32.

1-Chlorohepta-4,6-diyne-7-carboxylic acid isopropylamide. This was obtained from 1-chlorohepta-4,6--diyne through a series of transformations similarly to octa-5,7-diyne-8-carboxylic acid isopropylamide, but without using the cupric salt. It was purified by filtering its solution in a mixture of benzene and petroleum ether (2:1) through aluminum oxide. The solvent was removed in vacuo, and the residue was recrystallized from the same mixture, and then from a mixture of alcohol and benzene. A colorless, crystalline substance with m.p. 83°.

Found %: C 62.32, 62.12; H 6.63, 6.65; N 6.91. $C_{11}H_{14}ONCl$.

Calculated %: C 62.41; H 6.67; N 6.62.

SUMMARY

1. The condensations of diacetylene and butyldiacetylene with 1,3-chlorobromopropane have been carried out.

2. Derivatives of octa-5,7-diyne-8-carboxylic and 1-chlorohepta-4,6-diyne-7-carboxylic acids have been prepared for the purpose of biological testing.

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INTERACTION OF CYCLOPROPANE HYDROCARBONS WITH
MERCURIC SALTS

X. ACTION OF MERCURIC ACETATE ON (0,1,3)-BICYCLOHEXANES

R. Ya. Levina, V. N. Kostin, Kim Dyal Gir and T. K. Ustynyuk

Moscow State University

Original article submitted May 25, 1958

In our preceding works [1-4], a reaction was described, which is characteristic of cyclopropane hydrocarbons, and takes place with opening of the three-membered ring — the reaction with mercuric acetate in aqueous or alcoholic solutions.

By study of the products of this reaction — γ-mercurated alcohols and their ethers — it was established that the rupture of the three-membered ring takes place between the most- and least-substituted carbon atoms, for instance:
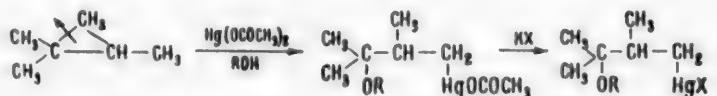
where $OR = OH$, OCH_3, OC_2H_5; $X = Cl$, Br, J, CN, CNS.

The crystalline organomercury compounds formed may well be used for identification of cyclopropane hydrocarbons.

In the present work, it was established that the reaction with mercuric acetate is also characteristic of "bridged" bicyclic hydrocarbons containing a three-membered ring, including (0,1,3)-bicyclohexanes.

On reaction of 1,3-dimethyl-(0,1,3)-bicyclohexane (I) and 1,3,5-trimethyl-(0,1,3)-bicyclohexane (II) with mercuric acetate in aqueous or methanolic solutions, and subsequent treatment with potassium salts, crystalline organomercury compounds are formed, which consist of cyclopentanols mercurated in the side chain, or their methyl ethers (III) and (IV):

where $OR = OH$ & OCH_3; $X = Cl$, Br, I, CN, CNS.
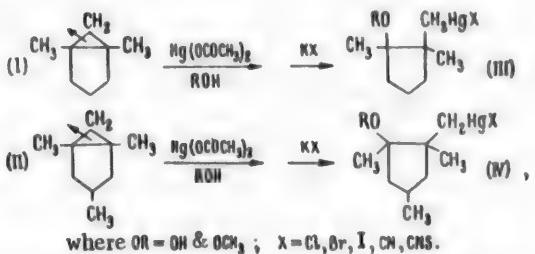
The structure given for the organomercury compounds formed (III) and (IV) was proved by the conversion of one of them — 2-hydroxy-1-chloromercurimethyl-1,2-dimethylcyclopentane — to 1,1,2-trimethylcyclopentanol-2 on reduction with butylmagnesium bromide [3]; the product was identified through its crystalline hemihydrate, and also through the Raman spectrum of the unsaturated hydrocarbon obtained from it on dehydration:
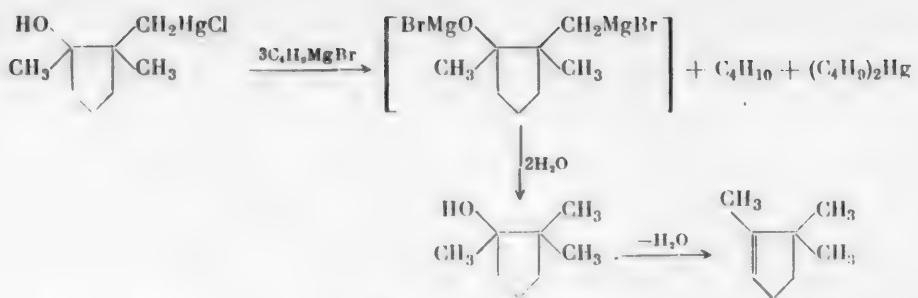
1-Methyl-3-ethyl-(0,1,3)-bicyclohexane (V) also can be identified by preparing the crystalline organomercury compound (VI) through successive treatment of this hydrocarbon with aqueous mercuric acetate solution and potassium bromide.
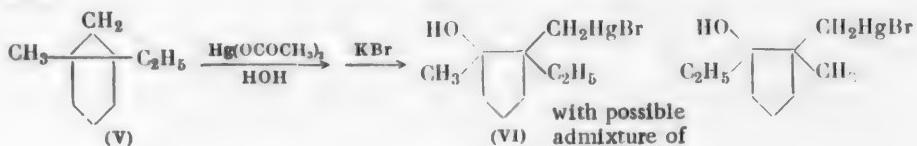
On treatment of other homologs of (0,1,3)-bicyclohexane — 1-methyl-3-alkyl-(0,1,3)-bicyclohexanes (where alkyl is C_3H_7, iso-C_3H_7, or C_4H_9) — with mercuric acetate (in aqueous or methanolic solution) there were obtained mercuriacetates, which were yellow oils; crystalline organomercury compounds could not be obtained by further treatment of the latter with potassium salts.

EXPERIMENTAL

Organomercury Compounds from 1,3-Dimethyl-(0,1,3)-Bicyclohexane

1,3-Dimethyl-(0,1,3)-bicyclohexane [5] (55 g, b.p. 110° at 768.5 mm, $n^{20}D$ 1.4360, d^{20}_4 0.8056) was shaken for 2 days at room temperature with mercuric acetate (147.7 g in 550 ml of water, or in 1200 ml of anhydrous methanol). To remove the mercury salts, both solutions were treated with alkali, filtered, and acidified with acetic acid. The mercuriacetates formed — 2-hydroxy- and 2-methoxy-1-acetoxymercurimethyl-1,2-dimethylcyclo-pentane — were isolated (yields 92 and 80%, respectively) in the form of oils after the acetic acid and water or methanol were distilled off in vacuo.

To an ice-cooled aqueous solution of the first mercuriacetate, or to an emulsion of the second in water, a cooled aqueous solution of an equivalent quantity of potassium chloride, bromide, iodide, cyanide, or thiocyanate was gradually added with vigorous stirring. The precipitated crystalline organomercury compounds were washed with water, dried in a desiccator over calcium chloride, and recrystallized from alcohol. Melting points and analytical data are given in Table 1.

The reduction of one of the γ-mercurated alcohols (III; OR = OH; X = Cl) for the purpose of proving its structure was carried out in the following manner.

To a water-cooled, ethereal solution of butylmagnesium bromide (29.2 g of magnesium and 164 g of butyl bromide), a suspension of 145 g of the organomercury compound (2-hydroxy-1-chloromercurimethyl-1,2-dimethyl-cyclopentane) in 300 ml of absolute ether was gradually added with vigorous stirring. The reaction mixture was then heated for 8 hours. It was decomposed by pouring on ice and subsequent addition of 2 N acetic acid. The ether layer was drawn off and the water layer extracted with ether. The ether extracts were washed with water, alkali, and water again, and dried with magnesium sulfate. After the ether was driven off, the 1,1,2-trimethyl-cyclopentanol-2 obtained was distilled in vacuo (dibutylmercury remained in the distilling flask): b.p. 82-84° (50 mm); yield 6.6 g; 13% of theoretical; characterized by preparing (by addition of a drop of water), the hemi-hydrate, m.p. 58-59° (from ether).

Found %: C 69.80, 69.82; H 12.32, 12.26. $[C_8H_6O]_2 \cdot H_2O$.

Calculated %: C 69.73; H 12.41.

TABLE 1

γ-Mercurated Alcohols and their Ethers of Structure

$$\begin{array}{c} RO \quad CH_2HgX \\ CH_3 \\ \bigtriangleup \\ CH_3 \quad CH_3 \end{array}$$ from
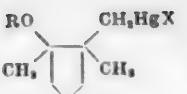
1,3-Dimethyl-(0,1,3)-Bicyclohexane

OR	X	Melting point	Found (%)			Calculated (%)		
			C	H	Hg	C	H	Hg
OH	Cl	117—118°	—	—	55.35	—	—	56.22
OH	Br	128—129	23.31, 23.20	3.83, 3.73	49.33	23.56	3.71	49.23
OH	I	124—125	21.30, 21.24	3.45, 3.44	—	21.15	3.30	—
OCH₃	Cl	89— 90	—	—	52.50	—	—	53.17
OCH₃	Br	100—101	25.32, 25.31	4.14, 4.08	—	25.63	4.06	—
OCH₃	I	131—132	—	—	42.75	—	—	42.79
OCH₃	CN	87— 88.5	—	—	54.95	—	—	54.53

TABLE 2

Raman Spectra of 1,1,2-Trimethylcyclopentene-2

Obtained in present work	According to literature data [7]
220 (1.5; b); 275 (2.5; b ; 348 (4);	224 (4); 274 (12); 349 (23);
434 (1); 566 (2.5); 648 (28);	431 (1); 566 (14); 652 (100);
698 (8); 792 (1.2); 822 (1);	699 (40); 793 (5); 823 (4);
887 (2); 920 (4; db/b	889 (9); 921 (31); 1022 (25);
930 (3; db/b);	
1019 (3.5); 1083—1108 (2; dif);	1109 (10); 1204 (25); 1226 (13);
1202 (4.5); 1227 (2.5); 1295 (3),	1295 (12); 1332 (10); 1389 (16);
1332 (2.5); 1388 (3);	
1440—1460 (10; db/b);1660 (30)	1452 (70); 1665 (70)

Note: Dif — diffuse line; db/b — double line on background;
b — broad line.

Literature data [6]: b.p. 80-81° (49 mm); m.p. of hemihydrate: 59-60°.

On distillation of 6.5 g of trimethylcyclopentanol over crystalline oxalic acid, there was obtained 4.3 g (87%) of 1,1,2-trimethylcyclopentene-2, which, after distillation over sodium, had the following constants.

B.p. 107-108° (744 mm), $n^{20}D$ 1.4310, d^{20}_4 0.7845.

Literature data [6]: b.p. 108.5-109° (754 mm), $n^{20}D$ 1.4324, d^{20}_4 0.7824.

Spectroscopic investigation confirmed the structure of the hydrocarbon obtained; the Raman spectrum contained the 1660 cm^{-1} band, characteristic of a substituted double bond in a five-membered ring.

In Table 2 is given the Raman spectrum of the 1,1,2-trimethylcyclopentene-2 obtained (with visually determined intensities, on an arbitrary scale in which the intensity of the 1440 cm^{-1} band is taken to be 10 units), with literature data for comparison.

Organomercury Compounds from 1,3,5-Trimethyl-(0,1,3)-Bicyclohexane

The opening of the three-membered ring of 1,3,5-trimethyl-(0,1,3)-bicyclohexane [5] (2 g, b.p. 125-125.5° at 735.5 mm, $n^{20}D$ 1.4335, d^{20}_4 0.7994) by mercuric acetate (5 g) was carried out in aqueous solution (20 ml of water) under the conditions stated above. The isolated reaction product (2-hydroxy-1-acetoxymercurimethyl--1,2,4-trimethylcyclopentane), a viscous oil, was converted by treatment with potassium salts in aqueous solution

TABLE 3

γ-Mercurated Alcohols of Structure

$$\begin{array}{c} HO \quad CH_2HgX \\ CH_3 \quad CH_3 \\ CH_3 \end{array}$$

from 1,3,5-Trimethyl-

-(0,1,3)-Bicyclohexane

X	Melting point	Found %			Calculated %		
		C	H	Hg	C	H	Hg
Cl	106—107	28.68, 28.66	4.49, 4.40	53.20	28.65	4.54	53.26
Br	117—118	25.81, 25.85	4.15, 4.03	—	25.63	4.06	—
I	103—104	23.59, 23.72	3.78, 3.66	—	23.06	3.66	—

to other organomercury compounds with the same carbon skeleton. Their melting points (af.er recrystallization from alcohol) and analytical data are given in Table 3.

Organomercury Derivative of 1-Methyl-3-Ethyl-(0,1,3)-Bicyclohexane

The opening of the three-membered ring of 1-methyl-3-ethyl-(0,1,3)-bicyclohexane [5] (2.5 g, b.p. 133.5 to 134° at 735 mm, $n^{20}D$ 1.4406, d^{20}_4 0.8165) by mercuric acetate in aqueous solution was carried out under the conditions stated above. The isolated reaction product, a viscous oil, was converted by treatment with potassium bromide to the mercuribromide (VI), m.p. 53-54° (from alcohol).

Found %: C 25.91, 25.97; H 4.07, 3.98. $C_9H_{17}OBrHg$.

Calculated %: C 25.63; H 4.06.

SUMMARY

1. It has been established that the reaction with mercuric acetate, which is characteristic of cyclopropane hydrocarbons, and takes place with rupture of the three-membered ring therein, is also characteristic of "bridged" bicyclic hydrocarbons containing three-membered rings.

2. It has been shown that rupture of the three-membered ring in homologs of (0,1,3)-bicyclohexane, occurring on treatment of the latter with mercuric acetate in aqueous or methanolic solution, does not take place on the carbon—carbon "bridge"; the products of this reaction are γ-mercurate (in the side chain) cyclopentanols, or their methyl ethers.

3. The preparation of crystalline γ-mercurated alcohols and their ethers may serve for the identification of 1,3-dimethyl-1,3,5-trimethyl- and 1-methyl-3-ethyl-(0,1,3)-bicyclohexanes.

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SYNTHESIS OF 4-HYDROXYMETHYLENE-2,2,5,5-
-TETRAALKYLFURANIDONES-3

I. K. Korobitsyna, T. A. Severina and Yu. K. Yur'ev

Moscow State University

Original article submitted May 9, 1958

In one of the preceding works [1], we showed that the most accessible β-diketone of the furanidine series — 4-acetyl-2,2,5,5-tetramethylfuranidone-3 — may be obtained by thermal isomerization of the enol acetate of 2,2,5,5-tetramethylfuranidone-3. In the present work, a method of synthesis of β-ketoaldehydes of the same series — 4-formyl-2,2,5,5-tetraalkylfuranidones-3 — is described.

We established that 2,2,5,5-tetraalkylfuranidones-3 condense with ethyl formate according to the Claisen reaction. On carrying out the reaction in absolute ether, using finely-divided sodium as the condensing agent, 4-hydroxymethylene-2,2,5,5-tetraalkylfuranidones-3 are formed in 56-66% yield:
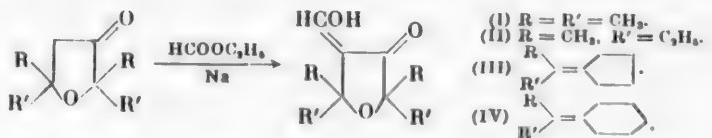
4-Hydroxymethylene-2,2,5,5-tetraalkylfuranidones-3 are crystalline substances which decompose in air within 2-3 days; they may be kept in dark containers for 3-4 weeks, the crude preparations being better preserved. They give an intense cherry-red coloration with ferric chloride solution, and form green cupric salts on treatment with cupric acetate solution. The absorption spectra of the cupric salts of 4-hydroxymethylene-2,2,5,5-tetra-alkylfuranidones-3 in the ultraviolet region, taken in methanol solution, have a λ_{max} in the 304-315 mμ range, which is characteristic of the cupric salts of β-dicarbonyl compounds. The percentage of enol form present was determined by the K. Meyer method [2] — direct titration of a solution of the 4-hydroxymethylene-2,2,5,5-tetra-alkylfuranidone-3 in methanol with a solution of bromine in the same solvent at −10°. The results obtained are given in the table.

Name	Enol content, (in %)
4-Hydroxymethylene-2,2,5,5-tetramethylfuranid-one-3	65.7
4-Hydroxymethylene-2,5-dimethyl-2,5--diethylfuranidone-3	81.5
4-Hydroxymethylene-2,2,5,5-bis(tetramethyl-ene)furanidone-3	86.5
4-Hydroxymethylene-2,2,5,5-bis(pentamethyl-ene)furanidone-3	91.2

The data given in the table show that β-ketoaldehydes of the 2,2,5,5-tetraalkylfuranidine series, as well as β-ketoaldehydes of the alicyclic series [3,4], consist of equilibrium mixtures of the formyl and hydroxymethylene forms, the latter greatly predominating.

The data given in the table also show that as the hydrocarbon radicals in positions 2 and 5 of the furanidine ring become larger, the enolization of the formyl group in position 4 increases. On acylation of a 4-hydroxymethylene-2,2,5,5-tetraalkylfuranidone-3 under the proper conditions, derivatives are formed both through oxygen and through carbon. Thus, on treatment of pyridine solutions of 4-hydroxymethylene-2,2,5,5-tetramethylfuranidone-3 (I), 4-hydroxymethylene-2,2,5,5-bis(tetramethylene)furanidone-3 (III), and 4-hydroxymethylene-2,2,5,5-bis(pentamethylene)furanidone-3 (IV) with benzoyl chloride, the corresponding O-benzoates (V, VII, and IX) were obtained.

Treatment of the sodium derivatives of these same hydroxymethylene ketones with benzoyl chloride led to the formation of C-derivatives, i.e., compounds containing three carbonyl groups on one carbon atom: 4-formyl-4-benzoyl-2,2,5,5-tetramethylfuranidone-3 (VI), 4-formyl-4-benzoyl-2,2,5,5-bis(tetramethylene)furanidone-3 (VIII), and 4-formyl-4-benzoyl-2,2,5,5-bis(pentamethylene)furanidone-3 (X).
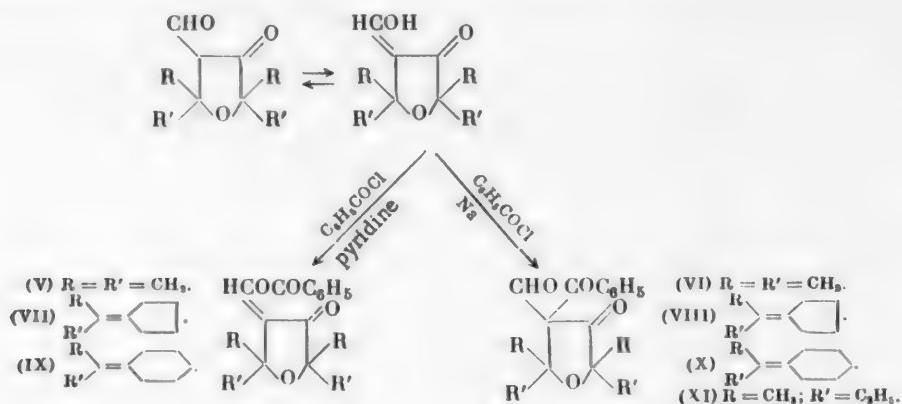
4-Hydroxymethylene-2,5-dimethyl-2,5-diethylfuranidone-3 (II) behaves somewhat differently, giving only one compound on benzoylation (regardless of conditions). On the basis of the data of elementary analysis, and the fact that this compound does not react with bromine, we ascribe to it the structure of 4-formyl-4-benzoyl-2,5-dimethyl-2,5-diethylfuranidone-3 (XI).

EXPERIMENTAL

4-Hydroxymethylene-2,2,5,5-tetramethylfuranidone-3 (I). To 4.6 g (0.2 mole) of finely-divided sodium in 150 ml of absolute ether in a three-neck flask provided with stirrer, reflux condenser, and dropping funnel, a mixture of 28.5 g (0.2 mole) of 2,2,5,5-tetramethylfuranidone-3 and 18.5 g (0.25 mole) of ethyl formate was slowly added at such a rate that the ether boiled uniformly. The reaction mass was stirred for 4 hours and left overnight. The separated sodium salt of 4-hydroxymethylene-2,2,5,5-tetramethylfuranidone-3 was filtered out by suction, washed with ether, dried in air, placed in a separatory funnel under a layer of absolute ether, and decomposed with 30% acetic acid. The ethereal extract was dried with anhydrous sodium sulfate. After the ether was driven off, 18 g (53%) was obtained.

M.p. 73-74° (from petroleum ether); b.p. 71-73° (11 mm).

Found %: C 63.42, 63.57; H 8.41, 8.47. $C_9H_{14}O_3$.

Calculated %: C 63.51; H 8.29.

4-Hydroxymethylene-2,2,5,5-tetramethylfuranidone-3 O-benzoate (V). To a solution of 1.7 g (0.01 mole) of 4-hydroxymethylene-2,2,5,5-tetramethylfuranidone-3 in 5 ml of pyridine was added 1.4 g (0.01 mole) of benzoyl chloride. The crystallized mass was thoroughly washed with warm water. Two g (73%) was obtained.

M.p. 97-98° (from alcohol).

Found %: C 69.99, 69.81; H 7.12, 7.03. $C_{16}H_{18}O_4$.

Calculated %: C 70.05; H 6.61.

4-Formyl-4-benzoyl-2,2,5,5-tetramethylfuranidone-3 (VI). To a solution of 7.8 g (0.046 mole) of 4-hydroxy-methylene-2,2,5,5-tetramethylfuranidone-3 in 40 ml of absolute ether in a flask provided with reflux condenser, stirrer, and dropping funnel, 1.1 g (0.046 mole) of sodium was added. The mixture was stirred, with heating, until the sodium was completely dissolved, 6.5 g (0.046 mole) of benzoyl chloride was then added, and heating was continued for 3 more hours. After 12 hours, the precipitate was filtered out by suction and washed with ether. After the ether was distilled from the combined ethereal extracts, 11.4 g was obtained (90.5%).

M.p. 82-84° (from alcohol).

Found %: C 70.03, 70.19; H 6.72, 6.80. $C_{16}H_{18}O_4$.

Calculated %: C 70.05; H 6.61.

4-Hydroxymethylene-2,5-dimethyl-2,5-diethylfuranidone-3 (II). To 4.6 g (0.2 mole) of finely-divided sodium in 150 ml of absolute ether in the apparatus described above, a mixture of 34.8 g (0.2 mole) of 2,5-dim-ethyl-2,5-diethylfuranidone-3 and 22 g (0.3 mole) of ethyl formate was added in such a way that the ether boiled uniformly. After stirring for 6 hours, the mixture was left overnight and then poured into 100 ml of water. The ether layer was drawn off and discarded; the water layer was neutralized with 30% acetic acid and extracted with ether. The ether extracts were dried with sodium sulfate. After the ether was distilled off, 26 g (66%) was obtained.

M.p. 57-58° (from petroleum ether).

Found %: C 66.82, 66.67; H 9.47, 9.29. $C_{11}H_{18}O_3$.

Calculated %: C 66.64; H 9.15.

4-Formyl-4-benzoyl-2,5-dimethyl-2,5-diethylfuranidone-3 (XI). This was prepared [as described for the preparation of (V)] from 4 g (0.02 mole) of 4-hydroxymethylene-2,5-dimethyl-2,5-diethylfuranidone-3 (II), 2.8 g (0.02 mole) of benzoyl chloride, and 5 ml of pyridine. Yield 5.9 g (quantitative).

M.p. 73.5-74.5° (from methanol).

Found %: C 71.62, 71.69; H 7.47, 7.32. $C_{19}H_{22}O_4$.

Calculated %: C 71.50; H 7.33.

4-Formyl-4-benzoyl-2,5-dimethyl-2,5-diethylfuranidone-3 was also obtained by treatment of the sodium derivative of 4-hydroxymethylene-2,5-dimethyl-2,5-diethylfuranidone-3 with benzoyl chloride (m.p. 73-74°; a sample, mixed with the substance obtained in the preceding experiment, showed no melting-point depression).

4-Hydroxymethylene-2,2,5,5-bis(tetramethylene)furanidone-3 (III) was prepared [as described above for the preparation of (I)] from 38.8 g (0.2 mole) of 2,2,5,5-bis(tetramethylene)furanidone-3, 22 g (0.3 mole) of ethyl formate, and 4.6 g (0.2 mole) of sodium. Yield 26 g (58.5%).

M.p. 103-104° (from petroleum ether).

Found %: C 70.37, 70.62; H 8.42, 8.47. $C_{13}H_{18}O_3$.

Calculated %: C 70.25; H 8.16.

4-Hydroxymethylene-2,2,5,5-bis(tetramethylene)furanidone-3 O-benzoate (VII) was prepared [as described for the preparation of (V)], from 3.3 g (0.015 mole) of 4-hydroxymethylene-2,2,5,5-bis(tetramethylene) furanid-one-3 (III) and 2.1 g (0.015 mole) of benzoyl chloride in 7 ml of pyridine. Yield 4.5 g (92%).

M.p. 110-111° (from alcohol).

Found %: C 73.84, 73.98; H 6.91, 6.93. $C_{20}H_{22}O_4$.

Calculated %: C 73.60; H 6.80.

4-Formyl-4-benzoyl-2,2,5,5-bis(tetramethylene)furanidone-3 (VIII). To a suspension of 2.5 g (0.01 mole) of the sodium salt of 4-hydroxymethylene-2,2,5,5-bis(tetramethylene)furanidone-3 (III) in 100 ml of absolute ether was added 1.4 g (0.01 mole) of benzoyl chloride. The reaction mixture was heated for 6 hr with stirring. After 12 hr the precipitate was filtered out with suction and washed with ether. After the ether was distilled from the combined ethereal extracts, 2 g (60%) was obtained.

M.p. 92-94° (from alcohol).

Found %: C 73.80, 73.71; H 7.00, 6.86. $C_{20}H_{22}O_4$.

Calculated %: C 73.60; H 6.80

4-Hydroxymethylene-2,2,5,5-bis(pentamethylene)furanidone-3 (IV) was prepared [as described for the preparation of (II)] from 44.4 g (0.2 mole) of 2,2,5,5-bis(pentamethylene)furanidone-3, 22 g (0.3 mole) of ethyl formate, and 4.6 g (0.2 mole) of sodium. Yield 28 g (56%).

M.p. 96-97° (from petroleum ether).

Found %: C 72.38, 72.33; H 9.00, 9.18. $C_{15}H_{22}O_3$.

Calculated %: C 71.97; H 8.86.

4-Hydroxymethylene-2,2,5,5-bis(pentamethylene)furanidone-3 O-benzoate (IX) was prepared [as described for the preparation of (V)] from 2.5 g (0.01 mole) of 4-hydroxymethylene-2,2,5,5-bis(pentamethylene)furanidone--3 (IV) and 1.4 g (0.01 mole) of benzoyl chloride in 7 ml of pyridine. Yield 3 g (85.5%).

M.p. 137-138° (from anhydrous alcohol).

Found %: C 74.59, 74.79; H 7.35, 7.37. $C_{22}H_{26}O_4$.

Calculated %: C 74.55; H 7.37.

4-Formyl-4-benzoyl-2,2,5,5-bis(pentamethylene)furanidone-3 (X) was prepared [as described for the preparation of (VI)] from 5 g (0.02 mole) of 4-hydroxymethylene-2,2,5,5-bis(pentamethylene)furanidone-3 (IV), 0.46 g (0.02 mole) of sodium, and 2.8 g (0.02 mole) of benzoyl chloride in 100 ml of absolute ether. Yield 5 g (70.5%).

M.p. 101-103° (from diluted alcohol).

Found %: C 74.55, 74.56; H 7.56, 7.55. $C_{22}H_{26}O_4$.

Calculated %: C 74.55; H 7.37.

SUMMARY

1. The ester condensation of 2,2,5,5-tetraalkylfuranidones-3 with ethyl formate in the presence of sodium leads to the formation of 4-hydroxymethylene-2,2,5,5-tetraalkylfuranidones-3.

2. Hydroxymethylene ketones of the 2,2,5,5-tetraalkylfuranidine series are enolized to a greater degree, the greater the number of carbon atoms in the radicals located in the 2,2- and 5,5-positions of the furanidine ring; under appropriate conditions, they form either C— or O— benzoyl derivatives.

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*Original Russian pagination. See C.B. translation.

CHEMISTRY OF SELENOPHENE

XVII. CONDENSATION OF 5-NITROSELENOPHENE-2-ALDEHYDE
WITH COMPOUNDS CONTAINING ACTIVE METHYLENE GROUPS

Yu. K. Yur'ev and E. L. Zaitseva

Moscow State University

Original article submitted May 9, 1958

In previous work [1] we showed that 5-nitroselenophene-2-aldehyde was readily obtained by nitration of selenophene-2-aldehyde in acetic anhydride with fuming nitric acid, containing 5-7% of concentrated sulfuric acid.

In the present work, 5-nitroselenophene-2-aldehyde was condensed with compounds containing active methylene groups, making it possible to obtain a series of 5-nitroselenal-2 derivatives. Thus, when 5-nitroselenophene--2-aldehyde was heated with acetic anhydride and anhydrous sodium acetate, we obtained β-(5-nitroselenienyl-2)--acrylic acid (42%).

We obtained the same acid by the condensation of 5-nitroselenophene-2-aldehyde with malonic acid in the presence of pyridine with subsequent decarboxylation of the α-carboxy-β-(5-nitroselenienyl-2)-acrylic acid formed:
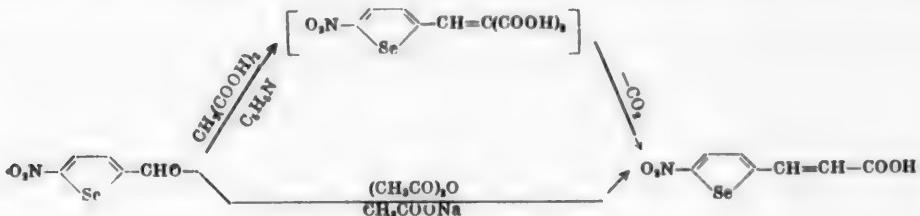
The interaction of 5-nitroselenophene-2-aldehyde with acetaldehyde, propionaldehyde and butyraldehyde in the presence of 25% potassium hydroxide in methanol led to the formation of aldol condensation products, namely, β-hydroxy-, α-methyl-β-hydroxy- and α-ethyl-β-hydroxy-β-(5-nitroselenienyl-2)-propionaldehyde, respectively. Without isolating the latter, we heated them with acetic anhydride and, as a result, obtained the products of crotonic condensation, β-(5-nitroselenienyl-2)-acrolein (68.5%), α-methyl-β-(5-nitroselenienyl-2)-acrolein (77.5%) and α-ethyl-β-(5-nitroselenienyl-2)-acrolein (82.5%):
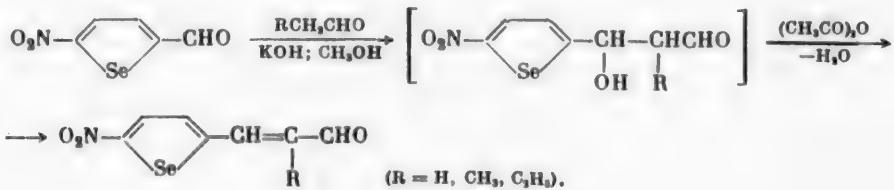
It should be noted that the condensation of 5-nitroselenophene-2-aldehyde with acetic anhydride required more drastic conditions than the analogous condensation of 5-nitrothiophene-2-aldehyde [2]: a higher concentration of the condensing agent and a longer time were required for completion of the reaction. Under the conditions given for 5-nitrothiophene-2-aldehyde, the condensation of 5-nitroselenophene-2-aldehyde with acetic anhydride did not occur at all. As regards the condensation of 5-nitrofurfural with aliphatic aldehydes [3-6], it occurred in a benzene medium in the presence of piperidine acetate and the products of aldol condensation readily lost water simply on heating to 40-50°.

Condensation of 5-nitroselenophene-2-aldehyde with nitromethane proceeded in the presence of aqueous sodium hydroxide solution and the α-(5-nitroselenienyl-2)-β-nitroethyl alcohol formed readily lost water when heated with acetic anhydride, giving ω-(5-nitroselenienyl-2)-nitroethylene:
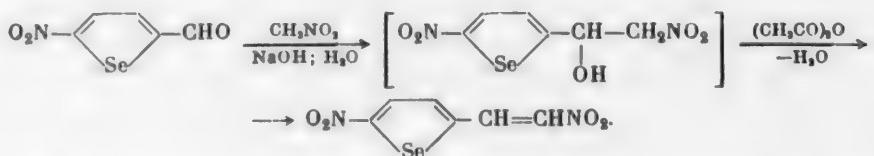
From the work of Z. N. Nazarova [7], describing the interaction of 5-nitrofurfural with nitromethane, it is evident that the aldol condensation product formed is unstable and loses water even in the cold, to give ω-(5--nitroselenienyl-2)-nitroethylene.

5-Nitroselenophene-2-aldehyde was condensed with rhodanine by the procedure described by Girard [8] for the corresponding condensations of ketones, which gave 30% yields. The yield of 5-(5-nitroselenenal-2)-thiazolidone-4-thione-2 was 29%.

The condensation of 5-nitroselenophene-2-aldehyde with hippuric acid led to 2-phenyl-4-(5-nitroselenenal--2)-oxazolone-5 (76.5%):
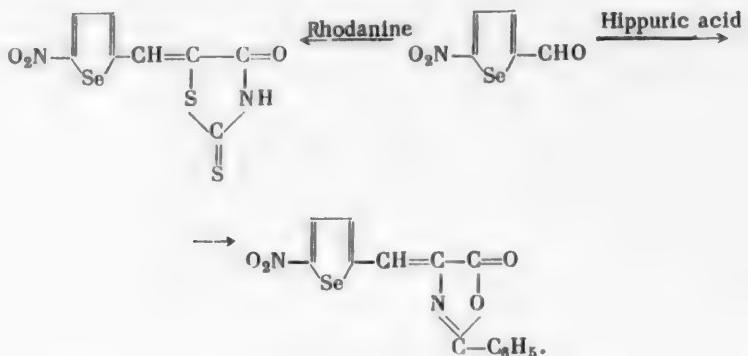
EXPERIMENTAL

β-(5-Nitroselenienyl-2)-acrylic acid. a) Into a round-bottomed flask with a reflux condenser with a calcium chloride tube was placed 2.04 g (0.01 mole) of 5-nitroselenophene-2-aldehyde, 3.47 g (0.042 mole) of anhydrous sodium acetate, and 9.9 g (0.097 mole) of acetic anhydride. The mixture was heated for 8 hours on an oil bath at 155-160°, cooled, diluted with 100 ml of water, neutralized with sodium carbonate, and filtered. The residue on the filter was washed with water until acidification of the wash waters no longer produced a precipitate. The combined filtrates were acidified with concentrated hydrochloric acid, and the precipitate collected and washed with water. We obtained 1.03 g (42%) of yellow needles: the m.p. was 252-253° (with decomp.) (from alcohol).

Found %: C 33.99, 34.13; H 2.22, 2.37; N 5.37, 5.50. $C_7H_5O_4NSe$.

Calculated %: C 34.16; H 2.04; N 5.69.

b) A mixture of 1.02 g (0.005 mole) of 5-nitroselenophene-2-aldehyde, 0.52 g (0.005 mole) of malonic acid, and 4.2 ml of dry pyridine was heated for 4 hours on a water bath in a flask with a reflux condenser. The reaction mixture was cooled, treated with 8 ml of saturated sodium carbonate solution, and filtered, the filtrate acidified with hydrochloric acid, and the precipitate collected and washed with water. We obtained 0.64 g (54.5%) of product; the m.p. was 252-253° (with decomp.). A mixed melting point with the acid described above was not depressed.

Methyl ester of β-(5-nitroselenienyl-2)-acrylic acid. A solution of 0.61 g (0.0025 mole) of β-(5-nitroselenienyl-2)-acrylic acid in 75 ml of anhydrous methanol was saturated with hydrogen chloride with cooling, and left for 2 hours. After removal in vacuum of 35 ml of alcohol, the residue was poured into 150 ml of water, treated with a solution of sodium bicarbonate, and the precipitate collected by filtration. We obtained 0.46 g (72%) of ester in the form of yellow platelets with m.p. 149-149.5° (from alcohol).

Found %: C 36.66, 36.57; H 2.97, 2.90; N 5.34, 5.46. $C_8H_7O_4NSe$.

Calculated %: C 36.93; H 2.71; N 5.38.

β-(5-Nitroselenienyl-2)-acrolein. Into a three-necked flask with a stirrer, thermometer, and reflux condenser, cooled to −5 to −7°, was placed 1.53 g (0.0075 mole) of 5-nitroselenophene-2-aldehyde and 3.67 g (0.083 mole) of acetaldehyde. With vigorous stirring, 0.55 ml of 25% potassium hydroxide in methanol was added dropwise. The brownish-red reaction mixture was stirred for 2.5 hours at 0 to +5°, and 2 hours at 30°, and then boiled for 20 minutes after 5.5 ml of acetic anhydride had been added to it. The mixture was cooled, treated with 25 ml of water and 2.5 ml of concentrated hydrochloric acid, boiled for 20 minutes, and left for 12 hours. The precipitate was collected by filtration, washed with cold water, and recrystallized from 65% acetic acid; dilution of mother solution with water yielded a further portion of the aldehyde as long yellow needles with m.p. 137.5-138° (from alcohol). The yield was 1.18 g (68.5%).

Found %: C 36.17, 36.32; H 2.30, 2.41; Se 34.13, 34.19. $C_7H_5O_3NSe$.

Calculated %: C 36.53; H 2.19; Se 34.31.

Semicarbazone of β-(5-nitroselenienyl-2)-acrolein. From 0.57 g of aldehyde, 0.28 g of semicarbazide hydrochloride, and 0.45 g of sodium acetate in 10 ml of water we obtained 0.72 g (quantitative yield) of yellow-orange crystals with m.p. 228-229° (with decomp.) (from dioxane).

Found %: C 33.85, 33.83; H 2.90, 2.87; Se 27.24, 27.15. $C_8H_8O_3N_4Se$.

Calculated %: C 33.47; H 2.81; Se 27.49.

Thiosemicarbazone of β-(5-nitroselenienyl-2)-acrolein. From 0.57 g of aldehyde and 0.25 g of thiosemicarbazide in 8 ml of alcohol with 5 drops of glacial acetic acid, and with the addition of 8 ml of water, we obtained 0.76 g (quantitative yield) of orange crystals with m.p. 240-242° (with decomp.) (from dioxane).

Found %: C 32.00, 32.04; H 2.87, 2.81. $C_8H_8O_2N_4SSe$.

Calculated %: C 31.69; H 2.66.

α-Methyl-β-(5-nitroselenienyl-2)-acrolein. This product was obtained as described above from 1.53 g (0.0075 mole) of 5-nitroselenophene-2-aldehyde and 3.81 g (0.065 mole) of propionaldehyde in the presence of 0.55 ml of 25% potassium hydroxide in methanol: the yellow needles had m.p. 139-139.5° after recrystallization from alcohol, and also after sublimation in a vacuum of 12 mm at 130-135°. The yield was 1.42 g (77.5%).

Found %: C 39.58, 39.41; H 2.92, 3.01; Se 32.24, 32.15. $C_8H_7O_3NSe$.

Calculated %: C 39.36; H 2.89; Se 32.34.

The semicarbazone of α-methyl-β-(5-nitroselenienyl-2)-acrolein was obtained from 0.61 g of aldehyde, 0.28 g of semicarbazide hydrochloride, and 0.45 g of sodium acetate in 10 ml of water. The yield was 0.75 g (quantitative). The yellow-orange crystals had m.p. 251-252° (with decomp.) (from alcohol).

Found %: C 36.22, 36.25; H 3.49, 3.59; Se 26.00, 25.89. $C_9H_{10}O_3N_4Se$.

Calculated %: C 35.89; H 3.35; Se 26.21.

α-Ethyl-β-(5-nitroselenienyl-2)-acrolein was obtained, as described above, from 1.53 g (0.0075 mole) of 5-nitroselenophene-2-aldehyde and 3.85 g (0.053 mole) of butyraldehyde in the presence of 0.55 ml of 25% potassium hydroxide in methanol: the yellow needles had m.p. 106.5-107° (from alcohol, after sublimation in vacuum at 12 mm and 145-150°). The yield was 1.59 g (82.5%).

Found %: C 42.14, 42.12; H 3.70, 3.64; Se 30.39, 30.33. $C_9H_9O_3NSe$.

Calculated %: C 41.88; H 3.51; Se 30.59.

The semicarbazone of α-ethyl-β-(5-nitroselenienyl-2)-acrolein was obtained from 0.64 g of aldehyde, 0.28 g of semicarbazide hydrochloride, and 0.45 g of sodium acetate in 10 ml of water. Yield 0.79 g (quantitative). The yellow crystals had m.p. 205-206° (with decomp.) (from alcohol).

Found %: C 38.17, 38.15; H 3.98, 4.09; Se 24.90, 24.87. $C_{10}H_{12}O_3N_4Se$.

Calculated %: C 38.11; H 3.83; Se 25.05.

ω-(5-Nitroselenienyl-2)-nitroethylene. With shaking, a solution of 0.13 g of sodium hydroxide in 0.8 ml of water was added dropwise to a solution of 1.53 g (0.0075 mole) of 5-nitroselenophene-2-aldehyde and 0.46 g (0.0075 mole) of nitromethane in 4.5 ml of methanol, cooled with ice and salt, the mixture left for 20 minutes and then poured with vigorous stirring into 20 ml of 5% hydrochloric acid, cooled to 0°, and extracted three times with ether. The extracts were dried with sodium sulfate, the ether removed in vacuum, and the residue boiled for 5 minutes with 4 ml of acetic anhydride. To the cooled mixture was added 25 ml of water and 1 ml of concentrated hydrochloric acid, the mixture heated to 80-90° for 20 minutes and then left for 12 hours in a refrigerator. The precipitate was collected by filtration, washed with water, and recrystallized from 65% acetic acid; dilution of the mother solution with water yielded a further portion of crystals: the yellow needles had m.p. 150-151° (from alcohol) and rapidly darkened in air. The yield was 0.6 g (32.5%).

Found %: C 29.07, 29.23; H 1.48, 1.53; Se 31.80, 31.75. $C_6H_4O_4N_2Se$.

Calculated %: C 29.16; H 1.63; Se 31.96.

5-(5-Nitroselenenal-2)-thiazolidone-4-thione-2. 1.53 g (0.0075 mole) of 5-nitroselenophene-2-aldehyde and 1 g (0.0075 mole) of rhodanine were dissolved in 15 ml of alcohol and 0.5 ml of concentrated ammonia and 0.5 g of ammonium chloride in 1.3 ml of water added. The mixture was heated for 15 minutes in a flask with a reflux condenser on a water bath at 60-65°, cooled, and diluted with 100 ml of water. The precipitate was collected by filtration, washed with water, dried and extracted with hot benzene. Removal of the benzene by distillation yielded 0.69 g (29%) of product: the long orange needles had m.p. 222.5-223.5° (with decomp.) (from acetone).

Found %: C 30.00, 29.86; H 1.37, 1.35; Se 24.79, 24.92. $C_8H_4O_3N_2S_2Se$.

Calculated %: C 30.10; H 1.26; Se 24.73.

2-Phenyl-4-(5-nitroselenenal-2)-oxazolone-5. 1.02 g (0.005 mole of 5-nitroselenophene-2-aldehyde, 0.89 g (0.005 mole) of hippuric acid, and 0.41 g (0.005 mole) of anhydrous sodium acetate in 14 ml of acetic anhydride were heated on a water bath for 30 minutes at 60-70°. The mixture was treated with 14 ml of water, and the precipitate collected and washed with alcohol. We obtained 1.32 g (76.5%) of yellow crystals with m.p. 244 to 245° (with decomp.) (from acetone).

Found %: C 48.48, 48.33; H 2.55, 2.50; Se 23.01, 22.95. $C_{14}H_8O_4N_2Se$.

Calculated %: C 48.13; H 2.32; Se 22.74.

SUMMARY

The condensation of 5-nitroselenophene-2-aldehyde with compounds containing active methylene groups led to 5-nitroselenenal-2 derivatives: β-(5-nitroselenienyl-2)-acrylic acid (by condensation with acetic anhydride or malonic acid), α-alkyl-β-(5-nitroselenienyl-2)-acroleins (by condensation with acetaldehyde, propionaldehyde, and butyraldehyde), ω-(5-nitroselenienyl-2)-nitroethylene (by condensation with nitromethane), 5-(5--nitroselenenal-2)-thiazolidone-4-thione-2 (by condensation with rhodanine), and 2-phenyl-4-(5-nitroselenenal--2)-oxazolone-5 (by condensation with hippuric acid).

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CHEMISTRY OF SELENOPHENE

XVIII. SYNTHESIS OF ISOMERIC TRIMETHYLSELENOPHENES AND TETRAMETHYLSELENOPHENE

Yu. K. Yur'ev, N. K. Sadovaya and M. A. Gal'bershtam

Moscow State University

Original article submitted May 9, 1958

In previous work [1], we described the synthesis of 2,3- and 2,4-dimethylselenophene. In continuing work on the synthesis of methyl homologs of selenophene, we utilized the possibility of successive formylation of the selenophene nucleus and reduction of the aldehyde to a methyl group for the preparation of further unknown isomeric trimethylselenophenes and tetramethylselenophene.

For the synthesis of 2,3,5-trimethylselenophene, we used 2,3-dimethylselenophene, from which we obtained 2,3-dimethylselenophene-5-aldehyde by the action of dimethylformamide by a previously described method [2]. Oxidation of this aldehyde with silver oxide gave 2,3-dimethylselenophene-5-carboxylic acid, and its reduction by the Kizhner general method [3] gave 2,3,5-trimethylselenophene:
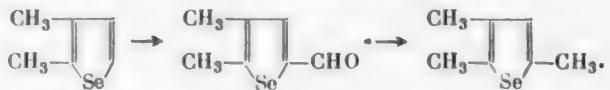
3,4-Dimethylselenophene was used as the starting material for the synthesis of 2,3,4-trimethylselenophene. Formylation of the former yielded 3,4-dimethylselenophene-2-aldehyde, which was oxidized to 3,4-dimethyl-selenophene-2-carboxylic acid, identical with that obtained previously by metallation of 2-iodo-3,4-dimethyl-selenophene with phenyllithium or magnesium with subsequent carboxylation of the organometallic compound formed [4-6].

Reduction of 3,4-dimethylselenophene-2-aldehyde yielded 2,3,4-trimethylselenophene. The latter, in its turn, served as the starting material for the synthesis of tetramethylselenophene. By formylation of 2,3,4-trimethyl-selenophene we obtained 2,3,4-trimethylselenophene-5-aldehyde, which formed 2,3,4-trimethylselenophene-5--carboxylic acid on oxidation, and 2,3,4,5-tetramethylselenophene on reduction:
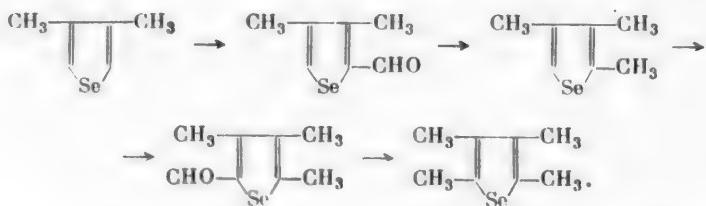
Of the two isomeric trimethyl seleophenes, only 2,3,4-trimethylselenophene underwent mercuration with the formation of 5-chloromercuri-2,3,4-trimethylselenophene; 2,3,5-trimethylselenophene did not undergo this reaction.

Synthesis of 2,3,5-Trimethylselenophene

2,3-Dimethylselenophene-5-aldehyde was obtained by the action of dimethylformamide on 2,3-dimethyl-selenophene (b.p. 159.5-160° at 756 mm [1]) in the presence of phosphorus oxychloride, as described previously [2]. From 23.8 g (0.15 mole) of 2,3-dimethylselenophene, 13.9 g (0.19 mole) of dimethylformamide and 28.16 g (0.19 mole) of phosphorus oxychloride, we obtained 18.4 g (66%) of aldehyde.

B.p. 114-115° (12 mm), $n^{20}D$ 1.6106, d^{20}_4 1.4683, MR_D 44.08. $C_7H_8OSeF_2$. Calc. 42.01.

Found %: C 44.73, 44.76; H 4.34, 4.44. C_7H_8OSe.

Calculated %: C 44.94; H 4.31.

Semicarbazone of 2,3-dimethylselenophene-5-aldehyde: m.p. 242-243° (from 50% alcohol).

Found %: N 16.86, 16.82. $C_8H_{11}ON_3Se$.

Calculated %: N 17.20.

Thiosemicarbazone of 2,3-dimethylselenophene-5-aldehyde: m.p. 194.5-195° (from 50% alcohol).

Found %: N 14.92, 14.96. $C_8H_{11}SN_3Se$.

Calculated %: N 15.22.

2,4-Dinitrophenylhydrazone of 2,3-dimethylselenophene-5-aldehyde: m.p. 268-269° (from a mixture of alcohol and ethyl acetate).

Found %: N 15.41, 15.47. $C_{13}H_{12}O_4N_4Se$.

Calculated %: N 15.26.

2,3-Dimethylselenophene-5-carboxylic acid. 0.5 g of 2,3-dimethylselenophene-5-aldehyde was oxidized with an alkaline solution of silver oxide, obtained from 1 g of silver nitrate and 0.3 g of sodium hydroxide in 30 ml of 50% alcohol and 18 ml of water. We obtained 0.5 g (quantitative yield) of acid with m.p. 197-197.5° (from 50% alcohol).

Found %: C 41.63, 41.46; H 4.22, 4.12. $C_7H_8O_2Se$.

Calculated %: C 41.40; H 3.97.

2,3,5-Trimethylselenophene. 10.2 g (0.06 mole) of 2,3-dimethylselenophene-5-aldehyde, 10 g (0.2 mole) of hydrazine hydrate, and 6.1 g (0.15 mole) of sodium hydroxide in 60 ml of diethylene glycol were placed in a flask with a reflux condenser and heated for 2 hours on an oil bath at 130-180°, and then the reaction product was distilled from the reaction flask, dried, and redistilled. We obtained 5.4 g (52%) of product.

B.p. 179-180° (754 mm), $n^{20}D$ 1.5461, d^{20}_4 1.2980, MR_D 42.16. $C_7H_{10}SeF_2$. Calc. 42.00.

Found %: C 48.38; 48.48; H 5.91, 5.97. $C_7H_{10}Se$.

Calculated %: C 48.59; H 5.82.

2,3,5-Trimethylselenophene was not chloromercurated under the usual conditions.

Synthesis of 2,3,4-Trimethylselenophene

3,4-Dimethylselenophene-2-aldehyde. From 39 g (0.25 mole) of 3,4-dimethylselenophene (b.p. 168-168.5° at 745 mm [7]), 22.6 g (0.31 mole) of dimethylformamide and 47.5 g (0.31 mole) of phosphorus oxychloride, as described above, we obtained 41.5 g (94%) of aldehyde with m.p. 91-91.5° (from 50% alcohol).

Found %: C 44.88, 44.86; H 4.38, 4.25; Se 39.08, 39.04. C_7H_8OSe.

Calculated %: C 44.94; H 4.31; Se 39.26.

Semicarbazone of 3,4-dimethylselenophene-2-aldehyde: m.p. 213.5-214° (from 50% alcohol).

Found %: Se 32.48, 32.39. $C_8H_{11}ON_3Se$.

Calculated %: Se 32.21.

Thiosemicarbazone of 3,4-dimethylselenophene-2-aldehyde: m.p. 209-210° (with decomp.) (from 50% alcohol).

Found %: C 36.26, 36.33; H 4.38, 4.42; Se 30.40, 30.31. $C_8H_{11}SN_3Se$.

Calculated %: C 36.08; H 4.26; Se 30.23.

2,4-Dinitrophenylhydrazone of 3,4-dimethylselenophene-2-aldehyde: m.p. 254.5-255° (from a mixture of alcohol and ethyl acetate).

Found %: Se 21.65, 21.45. $C_{13}H_{12}O_4N_4Se$.

Calculated %: Se 21.51.

3,4-Dimethylselenophene-2-carboxylic acid. 0.5 g of 3,4-dimethylselenophene-2-aldehyde was oxidized with an alkaline solution of silver oxide, as described above. We obtained 0.5 g (quantitative yield) of acid with m.p. 183-183.5° (from 50% alcohol). A mixed melting point with authentic 3,4-dimethylselenophene-2-carboxylic acid, obtained previously [4-6], was not depressed.

2,3,4-Trimethylselenophene was obtained from 31.5 g (0.169 mole) of 3,4-dimethylselenophene-2-aldehyde, 35 g (0.7 mole) of hydrazine hydrate, and 20.4 g (0.5 mole) of sodium hydroxide in 200 ml of diethylene glycol, as described above, to give a yield of 21.4 g (74%).

B.p. 189-189.5° (745 mm), $n^{20}D$ 1.5552, d^{20}_4 1.3302, MR_D 41.60; $C_7H_{10}SeF_2$. Calc. 42.00.

Found %: C 48.31, 48.32; H 5.53; 5.64. $C_7H_{10}Se$.

Calculated %: C 48.59; H 5.82.

5-Chloromercuri-2,3,4-trimethylselenophene, obtained by the action of mercuric chloride on 2,3,4-trimethylselenophene in an aqueous alcohol solution in the presence of sodium acetate, melted at 185-186° (rapid heating).

Found %: Hg 49.35, 49.48. $C_7H_9HgClSe$.

Calculated %: Hg 49.14.

Synthesis of 2,3,4,5-Tetramethylselenophene

2,3,4-Trimethylselenophene-5-aldehyde. From 18.8 g (0.11 mole) of 2,3,4-trimethylselenophene, 9.9 g (0.13 mole) of dimethylformamide, and 19.84 g (0.13 mole) of phosphorus oxychloride, as described above, we obtained 17 g (77%) of aldehyde with m.p. 60-61° (from 50% alcohol).

Found %: C 47.50, 47.52; H 4.98, 4.99. $C_8H_{10}OSe$.

Calculated %: C 47.76; H 4.97.

Semicarbazone of 2,3,4-trimethylselenophene-5-aldehyde: m.p. 249-250° (with decomp.) (from dioxane).

Found %: Se 30.30, 30.20. $C_9H_{13}ON_3Se$.

Calculated %: Se 30.58.

Thiosemicarbazone of 2,3,4-trimethylselenophene-5-aldehyde: m.p. 242-243° (from dioxane).

Found %: C 39.49, 39.34; H 4.67, 4.72; Se 28.85, 28.83. $C_9H_{13}SN_3Se$.

Calculated %: C 39.41; H 4.77; Se 28.80.

2,4-Dinitrophenylhydrazone of 2,3,4-trimethylselenophene-5-aldehyde: m.p. 259.5-260° (from dioxane).

Found %: Se 20.51, 20.68. $C_{14}H_{14}O_4N_4Se$.

Calculated %: Se 20.71.

2,3,4-Trimethylselenophene-5-carboxylic acid. By oxidation with an alkaline solution of silver oxide, as described above, from 0.5 g (0.002 mole) of 2,3,4-trimethylselenophene-5-aldehyde we obtained 0.5 g (quantitative yield) of acid with m.p. 202-202.5° (from 50% alcohol).

Found %: C 44.26, 44.29; H 4.74, 4.85. $C_8H_{10}O_2Se$.

Calculated %: C 44.24; H 4.64.

2,3,4,5-Tetramethylselenophene. From 15.5 g (0.07 mole) of 2,3,4-trimethylselenophene-5-aldehyde, 15.5 g (0.31 mole) of hydrazine hydrate and 9.3 g (0.23 mole) of sodium hydroxide in 100 ml of diethylene glycol, we obtained 6.9 g (48%) of product, as described above.

B.p. 205.5-206° (748 mm), $n^{20}D$ 1.5510, d^{20}_4 1.2790, MR_D 46.68. $C_8H_{14}SeF_2$. Calc. 46.61.

Found %: C 51.52, 51.42; H 6.40, 6.58. $C_8H_{12}Se$.

Calculated %: C 51.33; H 6.41.

SUMMARY

1. Successive formylation of 2,3- and 3,4-dimethylselenophene and reduction of the aldehydes formed by Kizhner's method made it possible to obtain 2,3,4- and 2,3,5-trimethylselenophenes, and also, 2,3,4,5-tetramethylselenophene, which have not been described in the literature.

2. The intermediate products in the reactions given were 2,3-dimethylselenophene-5-aldehyde, 3,4-dimethylselenophene-2-aldehyde and 2,3,4-trimethylselenophene-5-aldehyde. Oxidation of these led to 2,3-dimethylselenophene-5-carboxylic acid, 3,4-dimethylselenophene-2-carboxylic acid and 2,3,4-trimethylselenophene-5--carboxylic acid, respectively.

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*Original Russian pagination. See C.B. translation.

THERMAL DECARBOXYLATION OF METHYL ACETYLSALICYLATE LABELED WITH C[14]

V. G. Vasil'ev and E. N. Kharlamova

L. Ya. Karpov Physicochemical Scientific Research Institute

Original article submitted April 15, 1958

The decarboxylation of carboxylic acids has been studied in very great detail. Brown [1] presented a series of proofs showing that these reactions proceed through the formation of an anion or a dipolar ion:

$$RCO_2H \longrightarrow RCO_2^- \longrightarrow R^- + CO_2, \tag{1}$$

$$RCO_2H \longrightarrow H^+RCO_2^- \longrightarrow RH + CO_2. \tag{2}$$

$$H^+ + RCO_2^- \longrightarrow HR + CO_2. \tag{3}$$
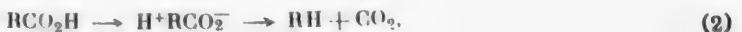
The single example of decomposition in the undissociated form is that of mesitoic acid, and the assumption of CO_2H^+ as an intermediate product is quite controversial:

$$H^+ + RCO_2H \longrightarrow HR + CO_2H^+ \longrightarrow HR + CO_2 + H^+. \tag{4}$$

The thermal decarboxylation of esters is a more complex process. Here, the two ruptured bonds have approximately equal strength.* Ionization of the RCOO—R' bond is hindered by the high formation energy of R'^+. Therefore, an ester can hardly decarboxylate by Routes (1)-(3). Rupture into radicals at the R—COO—R' bonds is improbable, despite the formation of the stable CO_2 molecule from the —COO— fragment; apparently, only a molecular mechanism can be considered.

The problems of the mechanism of this reaction, and the effect of the nature of the groups on the rupture of both bonds might possibly be solved by comparing the decarboxylation kinetics of esters of different structures. The difficulties connected with small expected differences, and the low accuracy of kinetic experiments may be avoided partially by the use of radioactive tracers. Let us assume that one molecule contains two decarboxylatable groups of different structures, one of which is labeled with the isotope of carbon C^{14} in the carboxyl. The ratio of

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* In ethers, the R—OR' bond is more stable than even the C—C bond in paraffins [2]. The RCOO—R' bond in esters is probably slightly weaker than the C—C bond, but its relative strength is indicated by the fact that the pyrolysis of esters of carboxylic acids, for example:

$$CH_3COOC_2H_5 \longrightarrow CH_3COOH + C_2H_4, \tag{5}$$

proceeds smoothly only when a double bond may be produced in the R' group in RCOOR'. Otherwise, the ester is found to be more stable, and decomposes by another route. Thus, phenyl acetate pyrolyzes only at 625° and not at 430-500° like alkyl acetates, and then the RCO—OR' bond is broken [3]. The energy for rupture of the C—O bond in alcohols and acids (~90 kcal/mole) is also greater than that of the C—C bond in paraffins (63-83 kcal per mole) [4].

the decarboxylation rate of the labeled and unlabeled groups may be determined readily by dividing the isotope content of the CO_2 liberated by that of the original molecule. From this ratio, it is easy to determine the difference in the activation energies of the two processes and to use this for finding one of the two activation energies from the other. By such a method, it would be possible to avoid the bulk of the reasons for the nonreproducibility of experiments since, due to the two groups being in the same molecule, for the two parallel reactions, at least in the initial period, the number of collisions would be exactly the same, the steric factors would be very similar, etc.

In the present work, this general method was applied to the investigation of the kinetics and mechanism of the decarboxylation of methyl acetylsalicylate, labeled in the acetate group with C^{14}:

$$(6)$$

$$(7)$$
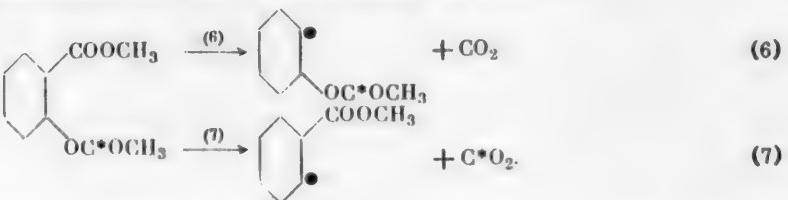
The two competing reactions are represented by (6) and (7).

One of the reasons for the choice of this substance was the fact that the two groups are in a position ortho to each other and, as is known, this facilitates decarboxylation. For example, methyl benzoate does not decompose, even after heating at 380-400° for 8 hours, while its o-hydroxy derivative (methyl salicylate) gives anisole and CO_2 even on heating to 300° [5].

EXPERIMENTAL

Syntheses of Starting Compounds

Methyl acetyl-1-C^{14}-salicylate (MA*S) was obtained by the scheme:
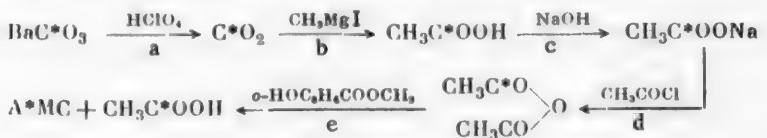
The optimal conditions were found by test syntheses.

Sodium acetate-1-C^{14} (stages a-c) was obtained on a 0.005 mole scale by a method developed on the basis of literature data [6], starting from a mixture of 0.102 g of BaC^*O_3 (335 μC) and 1.241 g of $BaCO_3$ (a total of 0.00682 mole). The yield was 73% with respect to $BaCO_3$. The total product from several parallel syntheses (0.013 mole, 655 μC) was used for stage (d).

Acetic anhydride-1-C^{14} (stage d) was obtained from a dry mixture of 1.07 g (0.013 mole) of CH_3C^*OONa, 3.63 g (0.0443 mole) of CH_3COONa, and 4.3 ml (0.0635 mole) of CH_3COCl. The yield of acetic anhydride-1-C^{14} was 72% (0.0415 mole).

Methyl acetyl-1-C^{14}-salicylate (stage e) was obtained by a modification of Erdmann's method [7] by boiling a dry mixture of 3.9 ml of

and 0.5 ml of $(CH_3CO)_2O$ (a total of 0.0466 mole), 5.8 ml (0.0452 mole) of methyl salicylate, 9 ml (0.1 mole) of benzene, and 0.1 g of camphorsulfonic acid [8] for 30 hr under reflux with protection from atmospheric moisture. The volatile components were distilled from the reaction product at about 20 mm Hg, and the vapors were collected in two traps at −78°. The residue was poured onto a watch glass, where the MA*S crystallized after several hours; the yield was 53% on stage (e); the total yield was 24.3% with respect to BaC^*O_3.
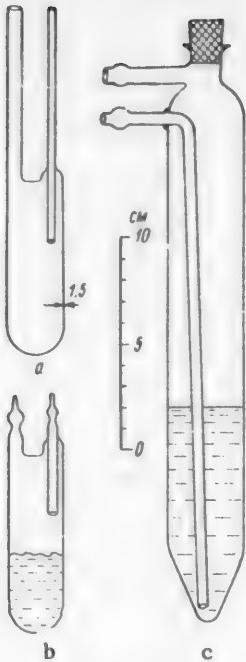
Fig. 1. Quartz ampules for investigating decarboxylation kinetics: a) blank ampule; b) ampule sealed off with substance; c) glass gas-scrubber for trapping CO_2.

The total radioactivity of the MA*S, according to this, must have been equal to $655 \cdot 0.243:2 = 80$ μC (half of the radioactivity was lost with acetic acid), and the molar radioactivity $a_m(MA*S) = 80:0.0246 = 3230$ μC/mole.

Unlabeled methyl acetylsalicylate was obtained by the same method from a mixture of 4 moles of methyl salicylate, 4 moles of acetic anhydride, 8 moles of benzene, and 0.02 mole of camphorsulfonic acid. The benzene and acetic acid were distilled from the reaction mixture at 100° and 500 mm Hg with nitrogen passed through the liquid and the residual acetic acid and unreacted material were evaporated with hot air (120°) in a countercurrent column (55 × 2 cm) with a packing of glass Fensky rings, 3-4 mm in diameter, heated to 120°. The MAS crystallized from the concentrate. After two recrystallizations from alcohol, the product was obtained as colorless, flaky crystals (3.1 moles; 77%); the m.p. was 49°, d^{100}_4 1.138 (lit. m.p. 48-49°).

Determination of Molar Radioactivity of MA*S

The molar radioactivity $a_m(MAS)$ was determined by combustion of MA*S and measurement of the radioactivity of a $BaC*O_3$ sample by a previously described procedure [9]. The sample thickness was always greater than the infinite value ($T \geq 25$ mg/cm^2) so that $G = 1$. In combustion of MA*S ($C_9C*H_{10}O_4$), the labeled $C*O_2$ was diluted ten times with unlabeled material and, therefore:

$$a_m(MA*S) = 10a_m(BaC*O_3) = 1.97 \cdot 10^6 K \frac{R}{G} \text{ μC/mole.} \tag{9}$$

The experiment gave the following results: $T = 27$ mg/cm^2, $G = 1$, $R = 4098$ counts/min, the calibration coefficient of the counter $K = 4.5 \cdot 10^{-7}$ μC · min/mg · count, and $a_m(MA*S) = 3620$ μC/mole, i.e., 112% of the calculated from the chemical yield (the 12% difference is caused by the inaccuracy of K, see [9]). In the experiments, we used MA*S with a radioactivity of 72.5 μC/mole, obtained by 50-fold dilution with inactive MAS.

Experimental Procedure

The decarboxylation was carried out by heating dry materials at constant temperature for a definite time in pure nitrogen at 2 mm Hg in sealed quartz* ampules (Fig. 1,b). The nitrogen for flushing the ampules was carefully freed from traces of oxygen, carbon dioxide, and water.

An ampule (Fig. 1a) was washed with hot chromic mixture, dried, baked at 300°, and cooled in a stream of nitrogen, and into it was introduced a weighed sample of MA*S. The left neck of the ampule was sealed off, as in Fig. 1,b. A double constriction was made in the right neck of the ampule. The ampule was pumped out to 2 mm and filled with nitrogen 6 times, pumped out again, and sealed off as in Fig. 1b.

The ampules were heated in a 300-Watt copper-block thermostat with pockets for ampules, thermometers, and a bimetallic spiral thermoregulator. The heating was regulated with an electrical relay by a normal circuit with an accuracy of ±1°; the difference in temperature between pockets was less than 1°. An ampule set in the heated block reached a temperature 1° less than the given one after 5 minutes. An ampule withdrawn from the block cooled to room temperature after approximately 1 minute.

The CO_2 was removed from the heated ampules by the following method. . The ends of the ampule were connected with rubber tubes, flushed with nitrogen: 1) to a source of nitrogen, and 2) to a U-shaped trap, cooled

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* By special experiments it was found that in glass ampules the reaction occurred mainly on the glass surface and, in quartz ones, in the volume.

Fig. 2. Kinetic curves of "conversion fraction x_6 —
— time τ " for the methyl carboxyl group of MA*S
at 280, 300, and 320°. Curves a are calculated by
Eq. (14); lines b from data on the constant k_1, and
curve c repeats the corresponding curve in Fig. 3.

to −78°, for trapping volatile pyrolysis products, and
to two gas-scrubbers (Fig. 1,c) with baryta water for
trapping CO_2. The ends of the ampule were broken
off inside the tubing (the inlet first), and the CO_2
flushed through into the traps with nitrogen for 20 to
30 minutes by heating the ampule in hot water. The
procedure of pumping out, sealing, heating, and re-
moving the CO_2 was repeated with the same portion
of MA*S in the given ampule for three successive
times to give three points for each kinetic curve. All
experiments were carried out with 3-5 samples of
MA*S. The weight and molar activity of the BaC*O_3
from the gas-scrubbers were determined as described
previously [9].

The calculations were carried out in the follow-
ing way: let n_6 be the number of moles of unlabled
CO_2, and n_7 the number of moles of labeled C*O_2
liberated. The molar radioactivity of the latter equals
the molar radioactivity of the MA*S taken. The
molar radioactivity of the mixture of n_6 moles of CO_2
and n_7 moles of C*O_2 is less than the molar radio-
activity of the starting MA*S by a factor of $n_6/(n_6+n_7)$.
The experiment gave the weight of the BaC*O_3 pre-
cipitate in the gas-scrubbers, from which $n_6 + n_7$ could
be found, and the molar radioactivity of the BaC*O_3,
from which we could find $n_6(n_6 + n_7)$ by dividing it by
the molar radioactivity of the MA*S. By calculating
n_6 and n_7 from this, and dividing them by the initial
number of moles of MA*S, we found the values of the
conversion fractions x_6 and x_7 for the two competing
reaction routes (6) and (7).

Kinetics of MA*S decarboxylation. The experi-
ments were carried out at 280, 300, and 320° in am-
pules (Fig. 1,b) with 5 g (0.0258 mole) samples of MA*S by the procedure described above.

Figure 2 shows the calculated kinetic curves $x_6 - f(\tau)$ and the experimental points for the liberation of CO_2
from the methyl carboxyl group of MA*S, and Fig. 3 gives the experimental curves $x_7 - f(\tau)$ for the liberation of
C*O_2 from the acetoxy group. The character of the curves is preserved at all temperatures, and the scatter of the
points is small. For comparison, the curve for x_7 at 300° is also given in Fig. 2. It is evident that initially the
rate of C*O_2 evolution exceeds the rate of CO_2 evolution by a factor of several, but then the liberation of CO_2 in-
creases and surpasses the liberation of C*O_2.

The course of the curves in Fig. 2 indicates autocatalysis. The autocatalyzing reaction product was appar-
ently not a phenol, since the addition of 3.2, 6.2, and 6.8 mole% of phenol did not increase the decarboxylation
rate of MA*S at 320°. With 3- and 9-fold dilution with anthracene, the rate of CO_2 evolution from MA*S (at
280°) increased considerably; the rate of C*O_2 evolution increased with 3-fold dilution and fell somewhat with
9-fold dilution. It is possible that the autocatalyst was a substance of the anthracene type. On the other hand,
with the transition from the polar molten MAS to a dilute solution in the nonpolar anthracene, the reaction rate
may change sharply (Menshutkin effect). We were unable to find a suitable solvent for determining the order of
reaction with respect to MAS; heavy paraffins were poor solvents of MAS, and aromatic compounds could be cata-
lysts. The order of reaction could only have been determined by experiments in dilute solution, for which larger
(and stronger) ampules, containing considerable amounts of MAS, would have been required. The existing pro-
cedure did not allow such experiments, and the order of reaction had to be estimated from indirect data.

Fig. 3. Kinetic curves of C^*O_2 evolution from the acetoxy groups of MA^*S at 280, 300, and 320°. Curves _a_ — experimental; lines _b_ — initial course of reaction.

Analogous results were obtained with MA^*S. A total of 21 g of MA^*S with a molar radioactivity of 395 μC/mole was heated at 260° for 1.5 hr in 3 ampules. Distillation of the product on the rotating column developed by Irlin and Bruns [12] gave the following fractions: 1st, 50-130°, containing acetone and acetic anhydride, and 2nd, 220-227°, containing methyl salicylate. The first fraction was hydrolyzed with aqueous ammonia. The acetone was removed from the ammonium acetate solution obtained by evaporation of the latter to a sirupy consistency. A sample of this solution was combusted, and the radioactivity of the C^*O_2 obtained was determined. Calculation of the molar radioactivity of the ammonium acetate from this showed that it was equal to 385 μC/mole, i.e., almost the same as that of the original MA^*S. Therefore, there is no doubt that the acetic anhydride was formed from the labeled acetoxy group of the MA^*S. When the separate products of MAS pyrolysis were heated under the same conditions, it was found that acetic acid was not decarboxylated; methyl salicylate and acetic anhydride were decarboxylated (the latter left a layer of tar on the glass).

DISCUSSION OF RESULTS

Since the molar radioactivity of the carbon dioxide liberated was less than that of the original MA^*S, the C^*O_2 from the acetoxy group was diluted by unlabeled CO_2 from the methyl carboxyl. Since under the experimental conditions there were no other sources of unlabeled CO_2, it is evident that both groups were decarboxylated simultaneously.

Decarboxylation of unlabeled methyl carboxyl group. The course of the curves in Fig. 2 may indicate either a chain radical mechanism or autocatalysis. The former is excluded since in interrupted reactions, for the extraction of CO_2, the contents of the ampules were heated at 100° for 20-30 minutes and free radicals could not remain in the liquid phase for this time; however, despite these intermediate heatings, all the curves were smooth. Therefore, this course may only be explained by the autocatalytic action of some stable reaction products.

However, autocatalysis cannot begin spontaneously; it must be initiated by another, even though slow, noncatalytic process. The latter may occur, for example, by the collision of two MA^*S molecules; the result is the formation of CO_2 and a product P_1, which, by further collision with another MA^*S molecule, also gives CO_2, and products among which is again P_1:

$$MA^*S \xrightarrow{k_1} CO_2 + P_1 \ldots, \tag{10}$$

$$MA^*S + P_1 \xrightarrow{k_2} CO_2 + 2P_1 \ldots \tag{11}$$

Then the rate of CO_2 evolution will equal:

$$d\,[CO_2]/d\tau = k_1\,[MA \cdot S] + k_2\,[MA \cdot S] \cdot [P_1].\tag{12}$$

Since P_1 and CO_2 are obtained in equimolecular amounts, $[P_1] = [CO_2]$. Substituting this in (12), dividing by $[MA \cdot S]$, and remembering that $x_6 = [CO_2] : [MA \cdot S]$, we obtain

$$dx_6/d\tau = k_1\,[MA \cdot S]\,\left(1 + \frac{k_2}{k_1}\,x_6\right) \cdot \tau.\tag{13}$$

In our experiments, $x_6 \leq 10\%$ and, therefore, the concentration $[MA \cdot S]$ may be taken as constant; since d^{100}_4 1.138, it equals 5.9 M. Equation (13) is then easily integrated:

$$\frac{2.3}{5.9 k_2}\,lg\left(1 + \frac{k_2}{k_1}\,x_6\right) = \tau.\tag{14}$$

The constants k_2 and k_1 for 320 and 300° were found by the method of iteration by substituting in (14) the coordinates of the "best" experimental points (marked with black circles in Fig. 2). For 320° we obtained the values $k_1 = 2.48 \cdot 10^{-7}$ liters $\cdot$ mole^{-1} $\cdot$ sec^{-1} and $k_2 = 3.68 \cdot 10^{-5}$ liters $\cdot$ mole^{-1} $\cdot$ sec^{-1}; for 300°, $k_1 = 6.64 \cdot 10^{-8}$ liters $\cdot$ mole^{-1} $\cdot$ sec^{-1}, and $k_2 = 1.58 \cdot 10^{-5}$ liters $\cdot$ mole^{-1} $\cdot$ sec^{-1}. The slight bend of the experimental curve for 280° did not allow such a calculation in this case, and the values $k = 1.75 \cdot 10^{-8}$ and $k_2 = 6.70 \cdot 10^{-6}$ liters $\cdot$ mole^{-1} $\cdot$ sec^{-1} were found by extrapolation from the graph of $lg\,k = f(1/T)$. Figure 2 shows that the experimental points for 280, 300, and 320° fit well on the curves a, calculated from Eq. (14) by substituting the values of k_1 and k_2 in it, and the lines b, drawn with a slope equal to k_1, satisfactorily express the initial period of the reaction according to Eq. (10). This confirms the hypothesis on the autocatalytic mechanism, and also the accuracy of the rate constants found, and makes it possible to calculate the activation energy. According to the data for 300 and 320°, for the noncatalytic reaction (10), $E_{a,10} = 44$ kcal/mole and for the catalytic reaction (11), $E_{a,11} = 38$ kcal/mole ($E_{a,11}$, naturally, was found to be less than $E_{a,10}$). For the preexponential factor, we obtained the reasonable values $(Pz_0)_{10} = 5 \cdot 10^9$ and $(Pz_0)_{11} = 6 \cdot 10^9$ liters $\cdot$ mole^{-1} $\cdot$ sec^{-1}.

The catalytic reaction (11) evidently must have a bimolecular character, but not the noncatalytic reaction (10), since, for Eq. (12) to be realized, it was only necessary that the first term specified by it should not depend on $[CO_2]$. However, the other alternative, i.e., monomolecular decomposition of MAS, apparently should require a much higher activation energy. Thus, the assumption of an ionic mechanism:

$$RCOOCH_3 \begin{array}{c} \nearrow R^- + CO_2 + CH_3^+ \searrow \\ \\ \searrow R^+ + CO_2 + CH_3^- \nearrow \end{array} CO_2 + P_1 + \ldots \tag{15}$$
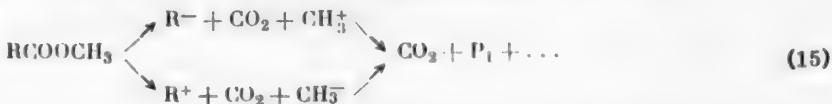
contradicts the well-known fact of the weak polarity of the $R-COOCH_3$ bond and the high formation energy of the intermediate ions for (15); for decomposition according to (16):

$$RCOOCH_3 \longrightarrow R\cdot + CO_2 + CH_3\cdot \longrightarrow CO_2 + P_1 + \ldots \tag{16}$$

the activation energy must be considerably higher than the experimental value.* Finally, the hypothesis (17):

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* There is no thermochemical data for MAS, but it is possible to give an evaluation for the analogous compound methyl benzoate. From its heat of combustion (950.8 kcal/mole [13]), and of evaporation (20.0 kcal/mole; this follows from the vapor pressure [14]) comes the heat of formation ΔH_f° ($C_6H_5CO_2CH_3$, gas) = −54.9 kcal/mole. Then, from the reactions C_6H_5Br (gas) → C_6H_5 (gas) + Br (gas) − 70.9 kcal/mole [15] and Na (gas) + C_6H_5Br (gas) → → NaBr (gas) + C_6H_5 (gas) + 16.7 kcal/mole [16], and from data for ΔH_f° of all the other components [17,18], it is possible to determine ΔH_f° (C_6H_5, gas) = 68.1 kcal/mole (according to Szwarc [19], 72 kcal/mole). Since ΔH_f° (CO_2) = −94.1 kcal/mole and ΔH_f° ($CH_3\cdot$) = 32.0 kcal/mole [17], then $E_{a,16} = 61$ kcal/mole.

$$\text{(17)}$$
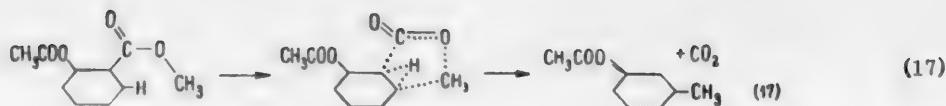
is opposed by the fact that m-toluyl acetate, designated as P_1 here, must be much more stable thermally than MAS (see data on phenyl acetate [3]), which contradicts Eq. (11).

Decarboxylation of labeled acetoxy group of MA•S. The evolution of labeled $C^\bullet O_2$ evidently proceeds in two stages:

$$2 MA^\bullet S \xrightarrow{k_3} (CH_3C^*O)_2O + P_2, \tag{18a}$$

$$(CH_3C^*O)_2O \xrightarrow{k_4} (CH_3)_2C^*O + C^*O_2. \tag{18b}$$

This is indicated by the following facts. 1) The synthesis of MAS, i.e., a reaction analogous to the reverse reaction (18a), is an equilibrium reaction according to literature [20] and our data; 2) methyl salicylate and labeled acetic anhydride were detected among the pyrolysis products of MA•S and it was shown that the acetic anhydride was formed from the two labeled acetoxy groups of MA•S; 3) the acetic anhydride appeared during the pyrolysis even at $t \le 240°$ and the $C^\bullet O_2$ only at $280°$; 4) at $280-300°$ acetic anhydride rapidly decomposes to CO_2 and acetone, and gives tars; the same substances were detected in the pyrolysis products of MA•S.

As Fig. 3 shows, the rate of $C^\bullet O_2$ evolution falls with time. This cannot be explained by exhaustion of the MA•S since the decomposition fraction x_7 did not exceed 3% in the experiments. The constants of the initial rates of $C^\bullet O_2$ evolution, calculated from the slope of the initial tangents to the curves by the equation $d[C^\bullet O_2]/d\tau = k_3[MA^\bullet S]^2$ were found to equal $k_3 = 1.28 \cdot 10^{-7}$ at $280°$, $k_3 = 2.43 \cdot 10^{-7}$ at $300°$, and $k_3 = 1.05 \cdot 10^{-6}$ liters $\cdot$ mole$^{-1} \cdot$ sec^{-1} at $320°$. Here, the lag of the curve behind the line (Fig. 3) for each of the temperatures (especially in the initial section) was approximately proportional to the value x_6 (Fig. 2), i.e., the concentration of the products of the parallel reactions. However, for different temperatures this proportionality was different. Thus, for example, at $320°$ there was approximately 1 unit of lag for each unit of x_6, while at $280°$ there were 5 units.

The characteristic of the $C^\bullet O_2$ evolution process presented may be explained if it is assumed that as the products of Reactions (10) and (11) are liberated, the labeled acetic anhydride combines with one of them in some sort of difficultly decarboxylatable compound [hence the fall in the rate of reaction (18) with time; see Fig. 3]; at a higher temperature, this compound is either decarboxylated more easily or is formed in lower concentration (hence the difference in the proportionality mentioned in going from 280 to 300 and to $320°$). On the graph of lg $k_3 = f(1/T)$, the points lie with a certain bulge toward the $1/T$ axis. This may indicate that, in addition to Reaction(18), there may be another route for the evolution of $C^\bullet O_2$ which has a similar rate but a higher activation energy; at lower temperatures, Route (18) predominates, and, at higher temperatures, this other process also starts to participate.

From the ratios of k_3/k_1 at 320, 300, and $280°$ (respectively equal to 7.31, 3.63, and 4.15), we obtained the values 2.2, 1.5, and 1.7 kcal/mole (average $\Delta E_a = 1.8$ kcal/mole) for the difference in the activation energy $\Delta E_a = (E_a)_{11} - (E_a)_{18a}$; the preexponential factors were taken as equal due to the similarity of the reactions and the structures of the two groups. Hence, the activation energy of (18a) equals $44 - 2 = 42$ kcal/mole.

An evaluation of the difference in the dissociation energies in reactions (10) and (18a):

$$\Delta D = [D(C_{aryl} - C_{carboxyl}) - D(CH_3 - C_{carboxyl})] +$$
$$+ [D(CH_3 - O_{ester}) - D(C_{aryl} - O_{ester})]$$

and, according to the empirical formula of Hirschfelder [21]: $E_a = 0.25 [D(A - B) + D(C - D)]$ for an exothermal bimolecular reaction of the type $AB + CD \rightarrow AC + BD$, gives $\Delta D = 6.5$ kcal/mole, with the larger part of it arising apparently from the first difference in the square brackets, since the links of the aryl and CH_3 with the carboxyl are very different. There are no data in the literature which make it possible to check this value or its distribution between the two components, but its order is correct.

SUMMARY

1. By means of the carbon isotope C^{14}, introduced into the acetoxy group, we studied the kinetics and mechanism of the homogeneous thermal decarboxylation of methyl acetylsalicylate (MAS) in a melt at 280, 300, and 320°. The use of the isotope made it possible to observe separately the rates of the simultaneous evolution of CO_2 from the two carboxyl groups of this compound.

2. The evolution of CO_2 from the methyl carboxyl group proceeded autocatalytically. The initial non-catalytic reaction proceeded with an activation energy of 44 kcal/mole. The autocatalytic stage proceeded between the MAS and the products of the first reaction with an activation energy of 38 kcal/mole. The kinetic curves calculated on the basis of these hypotheses agreed with experiment. Chain, radical, and ionic mechanism were excluded.

3. The evolution of C^*O_2 from the acetoxy group proceeded in two stages: first, two molecules of MAS formed acetic anhydride, which then decomposed to CO_2 and acetone. This reaction was slowed by the decomposition products of MAS.

4. From the ratio of the initial rate constants of C^*O_2 and CO_2 evolution, we calculated the difference in the activation energies of the two reactions as equal to 1.8 kcal/mole. This difference was mainly caused by the difference in the bond strengths of the two carboxyl groups with the aryl and methyl groups of the MAS molecule.

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ISOMERIZATION OF ETHYLCYCLOHEXANE ON GUMBRIN

V. V. Tishchenko and A. M. Belopol'skii

Leningrad State University

Received May 23, 1958

It was established [1] that, under the action of aluminum chloride, methylcyclohexane was hardly changed, while under these conditions, ethylcyclohexane was isomerized into dimethylcyclohexanes. Even earlier, Stratford [2] came to the same conclusion, and he showed that in the action of various amounts of aluminum chloride on ethylcyclohexane in the presence of hydrogen chloride, the main reaction product was 1,3-dimethylcyclohexane. Thus, the action of aluminum chloride on ethylcyclohexane is limited only to rupture of the radical and re-arrangement of its residue. Among the isomerization products of methylcyclohexane on a nickel—aluminosilicate catalyst at 286° under a hydrogen pressure of 24.8 atm, Chiapetta [3] detected the presence of n-butane, heptane, 1,1-, 1,2-, and 1,3-dimethylcyclopentanes and ethylcyclopentane. On the same catalyst at 286, 317, 343, and 372°, ethylcyclohexane was isomerized mainly into 1,1- and 1,2-dimethylcyclohexanes. Cyclopentane, and methane (from ethane to octane) and aromatic hydrocarbons were also found in considerably smaller amounts.

We previously showed [4] that on gumbrin, methylcyclohexane was isomerized into 1,2- and 1,3-dimethylcyclopentanes, which was not observed under the action of aluminum chloride. It seemed interesting to check whether this difference occurred in the action of aluminum chloride and that of gumbrin on ethylcyclohexane at temperatures below 250°.*

The data of the present work indicate that gumbrin has a stronger isomerizing action on ethylcyclohexane than on methylcyclohexane. The isomerization of ethylcyclohexane (like that of other naphthenes) is characterized first of all by conversion of the six-membered ring into a five-membered one, with subsequent rupture of the radical and intermolecular conversion of its residue. From the isomerization products of ethylcyclohexane it was possible to isolate mainly cyclopentane derivatives, namely, 1,2-methylethylcyclopentane (cis- and trans-), 1,2,3-trimethylcyclopentane (cis-cis-trans-), and 1,2,4-trimethylcyclopentane (cis-cis-trans-); the reaction products also contained dimethylcyclohexanes of undetermined structure, boiling in the range 119-124°. The degree of conversion of ethylcyclohexane on gumbrin at 250° reached 49-50%, and cyclopentane hydrocarbons represented 32-33% of the products and cyclohexane hydrocarbons, 16-17%. On the basis of the results obtained, the following isomerization scheme can be proposed:

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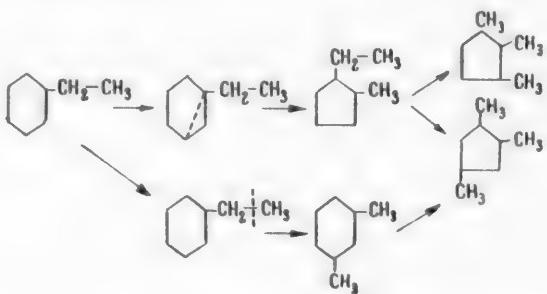
*The isomerization of hydrocarbons on natural aluminosilicon catalysts is of interest in connection with the problem of the conversion of petroleum in nature, and since the isostasy theory allows temperatures of not higher than 250°, this temperature was the limit at which experiments were performed.

EXPERIMENTAL

The starting ethylcyclohexane, prepared by hydrogenation of ethylbenzene, had the following constants.

B.p. 132.2°, d^{20}_4 0.7879, $n^{20}D$ 1.4329. Literature data [5]: b.p. 131.78°, d^{20}_4 0.7879, $n^{20}D$ 1.4330.

A qualitative reaction did not reveal the presence of aromatic hydrocarbons in the product obtained. The catalyst was gumbrin activated with 10% hydrochloric acid. The first experiment was carried out in a flask with a reflux condenser at the boiling point of ethylcyclohexane with equal-weight amounts of hydrocarbon and catalyst. Equilibrium (arbitrary) was considered reached when the refractive index of the liquid, which was measured after each 5 hr heating, did not change further. Experiment showed that at this temperature the isomerization proceeded very slowly and after 15 hr heating the refractive index had only changed to 1.4319; therefore, in subsequent experiments, which were carried out in an autoclave at high pressure, the reaction temperature was increased. The refractive index changed after 18 hr heating at the corresponding temperature in the following way: 175° — 1.4311, 200° — 1.4295, 225° —1.4275, and 250° — 1.4250. No gaseous products were observed. After the experiment, the isomerization product was separated from the catalyst and its aromatic hydrocarbon content determined by the aniline method; this varied over the range 0.60–0.91%, depending on the experimental temperature. After removal of the aromatic hydrocarbons by four distillations on a column with an efficiency of 18 theoretical plates, the product was separated into narrow fractions, depending on the boiling points of the hydrocarbons whose formation was expected. The following fractions were obtained:

1st B.p. to 104°, d^{20}_4 0.7602, $n^{20}D$ 1.4140, 1.3 g; due to the small amount, this was not examined in detail.

2nd B.p. 104-110.7°, d^{20}_4 0.7575, $n^{20}D$ 1.4150, 4.7 g, — 1,2,3-trimethylcyclopentane (cis-trans-cis-) (literature data [6]: b.p. 110.4°, d^{20}_4 0.7535, $n^{20}D$ 1.4144). The high specific gravity of the fraction may be explained by the presence of some components present in the 1st fraction.

3rd B.p. 110.7-112.7°, d^{20}_4 0.7608, $n^{20}D$ 1.4162, 1.5 g was a mixture of the 2nd and 4th fractions.

4th B.p. 112.7-117.5°, d^{20}_4 0.7636, $n^{20}D$ 1.4190, 3.7 g — the constants of this fraction agree well with those of 1,2,4-trimethylcyclopentane (cis-cis-trans-) (literature data [7]: b.p. 116.7°, d^{20}_4 0.7635, $n^{20}D$ 1.4186).

5th B.p. 117.5-119.7°, d^{20}_4 0.7701, $n^{20}D$ 1.4211, 9.5 g — this was 1,2,3-trimethylcyclopentane (cis-cis-trans-) (literature data [8]: b.p. 117.7°, d^{20}_4 0.7704, $n^{20}D$ 1.4219).

6th B.p. 119.7-121.2°, d^{20}_4 0.7763, $n^{30}D$ 1.4234, 15.9 g.

7th B.p. 121.2-123.0°, d^{20}_4 0.7771, $n^{20}D$ 1.4238, 12.7 g.

8th B.p. 123-127.5°, d^{20}_4 0.7850, $n^{20}D$ 1.4266, 11.4 g. In the last three fractions one might expect the presence of 1-methyl-3-methylcyclopentane (cis-), 1-methyl-3-ethylcyclopentane (trans-), 1-methyl-2-ethylcyclopentane (cis-) and 1,2,3-trimethylcyclopentane (cis-cis-cis-); however, the constants obtained do not agree with the constants of these hydrocarbons, which may be explained by the presence of various isomers of dimethylcyclohexane. In order to satisfy ourselves on this point, we combined the 6th, 7th, and 8th fractions and dehydrogenated them by Zelinskii's method over a nickel-aluminum catalyst. After removal of the aromatic hydrocarbons, we obtained 14 g of a product, which corresponded in constants to 1-methyl-2-ethylcyclopentane (trans-): b.p. 120 to 122°, d^{20}_4 0.7687, $n^{20}D$ 1.4214 (literature data [9]: b.p. 121.2°, d^{20}_4 0.7690, $n^{20}D$ 1.4119).

9th B.p. 127.5-130°, d^{20}_4 0.7848, $n^{20}D$ 1.4287, 7.3 g was similar in constants to 1-methyl-2-ethylcyclopentane (cis-) (literature data [10]: b.p. 128°, d^{20}_4 0.7852, $n^{20}D$ 1.4293). That the 9th fraction was identical with 1-methyl-2-ethylcyclopentane (cis-) was also confirmed by the Raman spectrum [11]: 343(4), 748(8), 789(2), 831(3), 1036(8), 1090(4), 1161(3), 1258(3), 1444(10). The intensities of the lines were evaluated visually according to a scale of ten.

SUMMARY

1. A study was made of the isomerization of ethylcyclohexane on gumbrin at 132, 175, 200, 225, and 250°. It was shown that under these conditions ethylcyclohexane was isomerized predominantly into cyclopentane hydrocarbons.

2. 1,2-Methylethylcyclopentane (cis-), 1,2-methylethylcyclopentane (trans-), 1,2,3-trimethylcyclopentane (cis-cis-trans-), and 1,2,4-trimethylcyclopentane (cis-cis-trans-) were isolated.

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* Original Russian pagination. See C.B. translation.

* * Russian translation.

* * * Transliteration of Russian — Publisher's note.

INTERACTION OF MERCURY CARBONATE AND ACETATE WITH HALOGENS. I.

S. S. Batsanov and M. S. Kontsevich

Moscow State University

Original article submitted April 15, 1958

Mercury is one of the few metals, whose chemistry is equally broadly represented by compounds of organic and inorganic origin. This peculiarity of mercury is caused by the predominantly covalent character of the bonds in its compounds, which is, to some extent, independent of its valence. In the inorganic chemistry of mercury, the latter circumstance appears as the possibility of the direct addition of oxidants to salts of monovalent mercury, without touching the previously available anions; by the direct action of halogens, Indian scientists in the 1920's obtained mixed salts of the type $Hg_2Y_nX_m$, where X is a halogen and Y a halogen of another sort, or a nitric or sulfuric acid residue [1,2].

The present work is devoted to an investigation of the interaction products of mercurous acetate and carbonate with halogens. Investigations in this field seem extremely promising to us, as by varying the oxidant it is possible to obtain a whole series of compounds from the same starting material, considerably extending the chemistry of mercury, and creating the possibility of synthesizing substances with previously set properties.

Interaction of Mercury Carbonate with Halogens

The action of gaseous chlorine on mercury carbonate powder in an alcohol medium quite rapidly (over a period of 1 hour) led to solution of the substance. Evaporation of the solution liberated yellowish white crystals, which dissolved in water and acids on heating, liberated mercury oxide in alkalis, and did not dissolve in the usual organic solvents. The density of this substance was 4.98 g/ml, and the refractive indices (n_D) equalled: n_p 1.740, n_m 1.821, and n_g 1.918.

These properties distinguish our compound from both the original carbonate and mercuric chloride, which could have been formed by a replacement reaction. Actually, Hg_2CO_3 is quite insoluble in water, and has (according to our measurements), a specific gravity of 8.73 and refractive indices above 2.00. Mercuric chloride is readily soluble in cold water, alcohol, and ether, and has a density of 5.44 and refractive indices of n_p 1.725, n_m 1.859, and n_g 1.969. Comparison of the properties showed that we were dealing with a new compound of mercury.

To determine the composition, we analyzed for mercury by the sulfide method, for chlorine ion by precipitation as AgCl, and for carbonate ion by precipitation as $BaCO_3$. The analysis results were as follows.

Found %: Hg 67.9; Cl 24.2; CO_3 8.3. $Hg_2CO_3Cl_4$.

Calculated %: Hg 66.5; Cl 23.5; CO_3 10.

Certain differences in the results of our analyses in this and in all the other cases were caused by the impurity of the starting mercury carbonate, whose carbonate content never exceeded 90% of the theoretical value [3].

For a conclusive solution to the problem, we made an x-ray investigation of the compound we obtained, and also of the original mercury carbonate, on which there is no data in the literature. Table 1 compares the interplanar distances of mercury carbonate, chloride, and chlorocarbonate [4]. The pictures were taken on an RKU camera (86 mm diameter) with copper radiation and an exposure time of 25 hours.

TABLE 1

Interplanar Distances in Mercury Carbonate, Chloride, and Chlorocarbonate

Hg$_2$CO$_3$Cl$_4$		HgCl$_2$				Hg$_2$CO$_3$			
intensity	d/n	intensity	d/n	intensity	d/n	intensity	d/n	intensity	d/n
weak	4.515	v.strong	4.35	weak	6.581	average	1.362	average	0.9377
average	3.003	average	4.10	v. weak	4.339	v. weak	1.335	weak	0.9324
weak	2.707	average	3.40	average	3.682	strong	1.320	average	0.9175
weak	2.438	weak	3.20	v.strong	3.297	weak	1.284	average	0.9051
weak	2.074	strong	3.00	weak	2.778	v. strong	1.244	average	0.8952
average	1.431	strong	2.70	weak	2.721	v. weak	1.207	weak	0.8615
weak	1.361	average	2.41	strong	2.462	average	1.193	v. weak	0.8522
average	1.325	v. weak	2.18	v. weak	2.571	average	1.166	weak	0.8499
weak	1.265	average	2.12	v. weak	2.360	weak	1.152	v. weak	0.8440
		average	2.06	strong	2.201	weak	1.139	weak	0.8423
		strong	2.00	v. weak	2.131	v. weak	1.111	weak	0.8302
		average	1.94	v. weak	2.047	weak	1.103	average	0.8290
		weak	1.90	strong	1.892	v. weak	1.083	v. weak	0.8172
		weak	1.79	v. weak	1.848	strong	1.075	weak	0.8138
		weak	1.67	average	1.726	average	1.055	strong	0.8093
		weak	1.62	v. weak	1.686	v. weak	1.027	average	0.8061
		weak	1.59	average	1.645	average	1.017	average	0.7952
		weak	1.54	weak	1.610	average	1.009	weak	0.7933
		weak	1.455	weak	1.535	v. weak	0.9892	strong	0.7869
		weak	1.400	v. weak	1.459	weak	0.9736	average	0.7849
		weak	1.340	average	1.418	weak	0.9608		

Table 1 shows that the x-ray picture of our compound had a definite specificity, although some lines were quite close to those of the corresponding interplanar distances in mercuric chloride. The latter is quite understandable since the composition of our compound was, in general, close to that of HgCl$_2$; the position is similar, for example, in the x-ray pictures of mercury sulfate and phosphate and other mercury compounds. The essential fact is that even when the numerical values of the x-ray lines were similar, their intensities differed sharply. All that has been said above indicated the individuality of the compound we synthesized.

At first glance, it seemed as if the composition of the mercury chlorocarbonate we obtained did not correspond to the mercury being in the divalent state. However, in the opinion of Naik and Avasare [1,2], who obtained analogous compounds by the halogenation of mercurous nitrate, this composition should be treated as perhalides (similar to KI$_3$). In this connection, it seemed interesting to compare the molecular volume of the compound we obtained with that of the original carbonate in order to determine the volume increment of chlorine in this substance.

The molecular volume of Hg$_2$CO$_3$ equals 52.8 ml/mole, and of Hg$_2$CO$_3$Cl$_4$, 121.1 ml/mole. Hence, one chlorine atom has 17 ml/mole. According to the data of Biltz [5], the volume of covalently bound chlorine equals 16.5 ml/mole, and that of ionic chlorine, 20 ml/mole. Consequently, an atom of chlorine in our compound has predominantly covalent bonds, which confirms the idea of the perhalide structure of this substance.

The molecular refraction of mercury chlorocarbonate equals 53.0 ml/mole. The total of the ionic refractions [6] equals 59.6 ml/mole, and that of the atomic refractions [7,8], 58.5 ml/mole. If it is assumed that the compound contains mercury and carbonate ions and Cl$_2^-$ radicals (i.e., the combination of an ion and an atom of chlorine), then the calculated value of the refraction becomes equal to 53.1 ml/mole.

Thus, refractometric data also confirm the hypothesis given above.

Mercury carbonate powder placed in an alcohol solution of bromine dissolved in a few minutes. Evaporation of the solution gave light brown crystals, which had a density of 5.94 g/ml and were insoluble in both water and organic liquids. The only acid they dissolved in was aqua regia and in alkalies they gave mercury oxide. The crystals were anisotropic and biaxial, but due to cleavage cracks it was only possible to determine two refractive

TABLE 2

Interplanar Distances of Mercury Bromide and Bromocarbonate

$Hg_2CO_3Br_5$		$HgBr_2$ [12]	
intensity	d/n	intensity	d/n
average	7.49	strong	6.2
average	6.12	weak	4.31
v. weak	2.660	strong	3.72
aver/weak	2.312	weak	2.96
v. weak	2.176	weak	2.51
strong/aver	2.068	average	2.31
v. weak	1.993	aver/weak	2.17
weak	1.960	weak	2.08
v. weak	1.915	average	2.03
v. weak	1.879	aver/weak	1.93
aver/weak	1.715	weak	1.88
v. weak	1.672	weak	1.83
strong	1.554	aver/weak	1.70
v. weak	1.538	weak	1.63
v. weak	1.471	aver/weak	1.55
weak	1.445	weak	1.490
v. weak	1.362	weak	1.451
aver/weak	1.293	weak	1.362
weak	1.238	weak	1.290
v. weak	1.229	weak	1.250
weak	1.105		
weak	1.079		
weak	1.067		

TABLE 3

Interplanar Distances of Mercury Iodide and Iodocarbonate

$Hg_2CO_3I_4$		HgI_4	
intensity	d/n	intensity	d/n
weak	6.564	average	6.192
weak	4.291	average	4.116
average	3.642	average	3.563
weak	3.492	weak	3.006
weak	3.050	aver/weak	2.756
v. weak	2.806	v. weak	2.523
v. weak	2.586	strong	2.183
strong	2.205	v. weak	2.063
average	2.077	weak	1.925
weak	2.017	aver/weak	1.863
average	1.938	v. weak	1.763
average	1.869	v. weak	1.647
weak	1.724	weak	1.541
weak	1.652	v. weak	1.499
weak	1.604	v. weak	1.454
weak	1.505	v. weak	1.416
weak	1.426	v. weak	1.375
v. weak	1.376	v. weak	1.343
weak	1.321	v. weak	1.313
average	1.268	weak	1.260
v. weak	1.219	v. weak	1.236
weak	1.155	v. weak	1.216
weak	1.125	v. weak	1.188
weak	1.098	v. weak	1.156
		v. weak	1.125
		v. weak	1.089
		v. weak	1.045

indices: n_p 1.864 and n_g > 2.00. These properties distinguish the compound obtained from the original carbonate and from mercuric bromide, which had a density of 6.05 g/ml and, in addition, is readily soluble in hot water and in alcohol.

In this case, analysis for mercury involved great difficulties, since the salt dissolved in aqua regia liberated mercuric chloride when heated. Since our compound was insoluble in any other solvent, analysis by classical methods was impossible.

The only analysis method consisted of treating the salt with a solution of concentrated alkali, which liberated mercury oxide. After neutralization, the filtrate was treated with hydrogen sulfide, and the rest of the mercury was precipitated as the sulfide. The results of the analysis are as follows.

Found %: Hg 46.2; Br 45.3. $Hg_2CO_3Br_5$.

Calculated %: Hg 46.6; Br 46.4

As previously, the discrepancy between calculations and experiment lay within the limits of the impurity of the starting material. The density of the mercury bromocarbonate was 5.94 g/ml.

We also made an x-ray examination of the compound synthesized with copper radiation in an RKU camera with an exposure of 40 hours. The results are presented in Table 2, where the interplanar spacings of mercuric bromide from Kitaigorodskii's data [4] are also given for comparison.

TABLE 4

Interplanar Distances in Mercury Acetate and Acetatohalides

$Hg_2(CH_3COO)_2$ [4]		$Hg_2(CH_3COO)_2Cl_4$		$Hg_2(CH_3COO)_2Br_5$		$Hg_2(CH_3COO)_2I_4$	
intensity	d/n	intensity	d/n	intensity	d/n	intensity	d/n
strong	13.0	weak	5.40	weak	7.05	weak	4.62
strong	11.5	weak	4.78	weak	6.44	average	4.217
average	3.86	weak	3.589	weak	2.342	average	3.627
weak	3.49	weak	3.396	weak	2.189	v. weak	3.409
weak	3.00	average	3.134	weak	2.059	average	3.033
v. weak	2.90	strong	2.847	weak	1.560	weak	2.830
v. weak	2.81	weak	2.531	weak	1.291	v. weak	2.548
v. weak	2.61	weak	2.451			average	2.458
v. weak	2.52	weak	2.205			weak	2.327
v. weak	2.42	weak	2.111			average	2.191
v. weak	2.36	strong	2.069			average	2.117
v. weak	2.24	weak	2.003			weak	2.028
v. weak	2.12	weak	1.960			v. weak	1.954
v. weak	2.01	weak	1.844			average	1.898
v. weak	1.93	weak	1.631			weak	1.787
v. weak	1.88	weak	1.569			weak	1.744
v. weak	1.85	strong	1.554			weak	1.661
v. weak	1.81					v. weak	1.618
v. weak	1.78					weak	1.598
v. weak	1.66					average	1.569
v. weak	1.62					av/weak	1.525
v. weak	1.60					weak	1.484
v. weak	1.55					weak	1.386
						average	1.322
						average	1.271

The character of the chemical structure of mercury bromocarbonate was the same as that of the corresponding chloride salt, i.e., this compound was also a perhalide. Data on the molecular volumes may be used to illustrate this hypothesis. The molecular volume of $Hg_2CO_3Br_5$ equals 144.9 ml/mole. As has already been said, mercurous carbonate has a molar volume of 52.8 ml/mole. Hence, each bromine atom occupies 18.4 ml/mole, which is close to the atomic volume of covalently bound bromine, 19.2 ml/mole, and differs considerably from the ionic volume increment of bromine, 25 ml/mole [5].

Generally speaking, an alcohol solution of iodine required quite a long time to dissolve mercurous carbonate, and from the solution it was possible to isolate red crystals of mercury iodocarbonate. However, this salt could be obtained more simply by careful fusion of Hg_2CO_3 with iodine. The compound obtained was not soluble in any medium apart from aqua regia, and had a specific gravity of 6.42 g/ml.

Mercuric iodide has a density of 6.28 g/ml and is quite noticeably soluble in anhydrous ethyl alcohol (even more so in methanol), and also in acetone and carbon disulfide. Consequently, the product from the interaction of mercury carbonate with iodine was a new compound.

Found %: Hg 43.7; I 49.5. $Hg_2CO_3I_4$.

Calculated %: Hg 41.4; I 52.4.

The deviation of the analysis results from the stoichiometric formula, which was caused by the fact that washing out the excess iodine (with benzene or alcohol) unavoidably also washed out a certain amount of "proper" iodine. This occurrence, which also appears, though to a lesser extent, in the case of the chloride and bromide salts, is a further indication of the perhalide structure of the compounds we synthesized.

The results of an x-ray examination of mercury iodocarbonate, made with copper radiation in an RKU camera with an exposure of 50 hours, are compared with literature data for mercuric iodide [4] in Table 3.

Table 3 shows that the x-ray picture of the iodocarbonate differs from that of mercuric iodide both in the numerical values of the lines (particularly the first), and in the intensities where the absolute dimensions of the interplanar distances are similar.

One can hardly expect a fundamental difference in the x-ray pictures of HgI_2 and $Hg_2CO_3I_4$, since the compositions of these compounds differ by only a few percent , namely by the weight of the CO_3 radical. Here, the difference in the intensities of similar lines is much more important, and this indicates that while the interplanar distances in the main structural motif of HgI_2 are retained, new atomic groupings (CO_3) appear, and these change the ratio of the intensities of the reflections from these atomic lattices.

The molecular volume of mercury iodocarbonate equals 150.9 ml/mole. Hence, one iodine atom occupies $\frac{1}{4} \cdot (150.9 - 52.8) = 24.5$ ml/mole, while, according to Biltz [5], the atomic volume of iodine equals 24.3 and the ionic increment 34 ml/mole. Consequently, the nature of the chemical bond in the iodocarbonate is the same as in the chlorine and bromine compounds.

Before concluding the description of the syntheses and properties of the halocarbonates, we should have another look at the composition of the bromine salt. Its composition is less symmetrical than that of the chloro- and iodocarbonates. We therefore carried out the synthesis several times so as to exclude the possibility of random errors. However, as a result of all experiments, we always obtained a salt with five atoms of bromine. Thus, it can be stated that bromine gives compounds more enriched in halogen than either chlorine or iodine. A comparison with the results of Naik and Avasare's investigations [1,2] shows that the peculiarity of bromine also appears in its interaction with mercury sulfate, where chlorine and iodine give compounds of the composition $Hg_2SO_3X_2$, and bromine Br_4, respectively. Below it will be shown that the acetatobromide also has the same composition in contrast to the chlorine and iodine salts. It is difficult to give an explanation of this behavior of bromine as yet, though undoubtedly it will be connected with geometric factors, which determine the packing density of the atoms in the crystal structure.

Interaction of Mercury Acetate with Halogens

The acetatohalogen salts of mercury were synthesized and analyzed by the same methods as the halocarbonate compounds. We will not describe them, therefore, but will only present the results of analysis and physico-chemical investigations of the substances obtained.

Mercury acetatochloride was a white powder with a density of 5.25 g/ml and refractive indices of n_g 1.966, n_m 1.941, and n_p 1.900. The substance dissolved readily in water and acids, was decomposed (with the evolution of HgO) by alkalies and also dissolved readily in alcohol, ether, and acetone, but was insoluble in benzene and toluene.

The mercury content was 60.5%, and that of chlorine 21.6%, which agrees with the formula $Hg_2(CH_3COO)_2Cl_4$. The molecular volume of mercury acetatochloride was 125.9 ml/mole, while the original acetate had a density of 4.64 and a molecular volume of 111.9 ml/mole. Hence, one atom of chlorine occupies only 3.5 ml/mole. Such a small volume for the volume increment is apparently caused by the openness of the structure of the acetate, into the spaces of which the chlorine atoms fit without an essential change in the molecular volume of the original substance.

The molecular refraction of mercury acetatochloride equals 60.2 ml/mole. The total of the ionic refractions (according to Fajans) equals 76.4 ml/mole, and the total of the atomic refractions (according to Vogel), equals 73.8 ml/mole. If we assume that this compound contains mercury and acetate ions and Cl_2^- radicals (i.e., the combination of a chlorine ion and atom), then the calculated value obtained equals 69.9 ml/mole. Thus, the minimal discrepancy with experiment occurs when a perhalide structure is assumed for the mercury acetato-chloride. The low value for the experimental molecular refraction is also (like the volumes) connected, apparently, with consolidation of the crystal structure when chlorine atoms are introduced into it.

The x-ray picture of mercury acetatochloride is illustrated by the figures in Table 4, together with the values of the interplanar distances for mercury acetatobromide and iodide. Analysis of the x-ray pictures shows the individuality of the compounds we synthesized.

Mercury acetatobromide was a grey powder with a specific gravity of 5.89 g/ml and refractive indices of n_p 1.872, n_g 2.00 (n_m was not determined due to complete cleavage cracking of the crystals). This compound was insoluble in water and organic solvents and among the acids, dissolved only in hot concentrated nitric acid and aqua regia.

Found %: Hg 43.5; Br 42.1. $Hg_2(CH_3COO)_2Br_6$.

Calculated %: Hg 43.7; Br 43.4.

The molecular volume of mercury acetatobromide equals 156 ml/mole. Hence, the volume increment of bromine equals 8.8 ml/mole, while the volume of a covalently bound bromine atom equals 18.2 ml/mole. Consequently, there is also contraction in the bromine salt, as in the chlorine salt, for the reasons noted above.

Mercury acetatoiodide was obtained by careful fusion of mercurous acetate with iodine. When the excess iodine had been washed out, crystals were obtained with a specific gravity of 6.52 g/ml and a refractive index above 2.00. Analysis gave the following results.

Found %: Hg 39.5; I 50.5. $Hg_2(CH_3COO)_2I_4$.

Calculated %: Hg 39.1; I 49.4.

The chemical properties of mercury acetatoiodide were similar to those of the bromine salt.

The molecular volume of $Hg_2(CH_3COO)_2I_4$ equals 157.5 ml/mole and hence the volume of iodine obtained was equal to 11.4 ml/mole. This value is also below the standard value of the volume increment of iodine (24.3 ml/mole) in complete accordance with the properties of mercury acetatochloride and bromide.

Data from the x-ray pictures of mercury acetatobromide and iodide are presented in Table 4, where the values of the interplanar distances for the original mercury acetate, taken from Kitaigorodskii's handbook [4], are given for comparison. A comparison of the x-ray pictures of the compounds obtained with the characteristics of the original salt and the corresponding mercury dihalides (see Tables 1-3) confirms the individuality of the substances synthesized.

As has already been stated, the x-ray investigation is the final proof of the individuality of the substances we synthesized.

SUMMARY

1. Mercury acetate and carbonate were halogenated, and, as a result, we synthesized perhalides of the composition $Hg_2CO_3Cl_4$, $Hg_2CO_3Br_6$, $Hg_2CO_3I_4$, $Hg_2(CH_3COO)_2Cl_4$, $Hg_2(CH_3COO)_2Br_6$, $Hg_2(CH_3COO)_2I_4$.

2. A study was made of the physicochemical properties of the substances obtained, including their x-ray pictures.

3. An x-ray picture of mercurous carbonate was taken for the first time, and the densities of mercury carbonate and acetate were measured.

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RADIOCHEMICAL INVESTIGATION OF RADICAL EXCHANGE IN CERTAIN SYSTEMS

I. A. Korshunov, R. V. Amenitskaya, A. A. Orlova

and A. P. Batalov

Gor'kii State University

Original article submitted December 9, 1957

In previous work [1], the radioactive isotope of carbon C^{14} was used to study the exchange of radicals in the systems diphenylmercury—benzene, phenylmercury hydroxide—benzene, and tetraphenyllead—benzene with heating and irradiation with ultraviolet light. Analysis of the experimental data showed that exchange of radicals may proceed by an open radical mechanism or through the intermediate formation of a reaction complex with the solvent. In addition, the extent of the exchange, which depended on the composition of the reacting system and the reaction conditions, made it possible to estimate the lability of the separate radicals in the compounds investigated.

In the present article, we present the results of studying the exchange of phenyl and ethyl radicals in the following systems:

$$C_6H_5HgBr-\overset{*}{C}_6H_5Br, \quad C_6H_5HgBr-\overset{*}{C}_6H_6, \quad C_6H_5MgBr-\overset{*}{C}_6H_5I \quad C_6H_5MgBr-\overset{*}{C}_6H_6,$$

$$C_2H_5MgBr-\overset{*}{C}_2H_5Br, \quad (C_2H_5)_4Pb-\overset{*}{C}_2H_5Br, \quad (C_6H_5)_4PI-\overset{*}{C}_6H_5I, \quad (C_6H_5)_4PJ-\overset{*}{C}_6H_6 \text{ and}$$

$$(C_6H_5)_2O-\overset{*}{C}_6H_6.$$
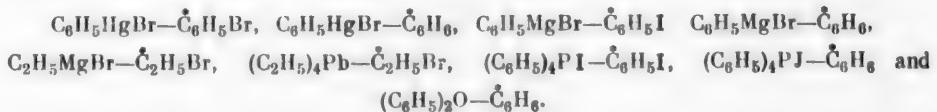
EXPERIMENTAL

For studying the exchange under ultraviolet irradiation, the starting materials were placed in quartz tubes and, in the case of heating, in pyrex tubes, which were sealed for each experiment. Irradiation was carried out with ultraviolet light from a mercury-quartz lamp, PRK-2. The irradiation time in each successive experiment was established in relation to the degree of exchange in the previous experiment. The contents of the tube were shaken periodically. For examining exchange at an elevated temperature, a hermetically sealed metal reactor was used, and in it were placed the tubes containing the exchangeable substances, solvent, and various additives. After irradiation with ultraviolet light or heating, the labeled bromobenzene (or benzene) was separated from the precipitate of phenylmercury bromide by decantation, distilled, and analyzed radiochemically. The residue was washed several times with unlabeled bromobenzene (or benzene) in the cold, and then 5-6 times with absolute ether. The chosen separation procedure was tested by special control experiments, in which the starting materials were mixed in the cold and separated under conditions which excluded exchange of radicals. In the study of the exchange in the system $C_6H_5HgBr-C_6H_5Br$ (or $\overset{*}{C}_6H_6$), the molecular ratio of the components was 1:40.

The labeled benzene required for the work was obtained by the method in [2]. Bromobenzene was synthesized from C^{14}-labeled benzene, and bromine by the usual method. Phenylmercury bromide was kindly provided by G. G. Petukhov.

The starting materials and reaction products were analyzed radiochemically after combustion of the organic substances to CO_2 by means of an internal-filling counter [3]. The accuracy of the analysis was evaluated as $\pm 3\%$.

TABLE 1

| System	Additives	Expt. conditions	Duration (hrs)	Activity (counts/ min) at 100% exch.	obtained in experiment	Degree of exch. (%)
$C_6H_5HgBr + \overset{\bullet}{C}_6H_5Br$	—	200°	160	648	39	6.0
	$CoCl_2$	210	10	813	354	43.5
	$CoCl_2$	100	10	813	163	20.0
	$CoCl_2$	25	10	813	124	15.3
	—		55	648	34	5.2
	—		10	648	9	—
	Ag		2	813	327	40.1
	Ag		10	643	456	71.0
	Ag		20	813	625	76.8
	$CoCl_2$	Irradiation with UV light	2	648	120	18.5
	$CoCl_2$		10	648	432	66.6
	$CoCl_2$		20	643	511	79.5
	$CoCl_2$		30	643	523	81.4
	$SnCl_2$		10	643	27	4.2
$C_6H_5HgBr + \overset{\bullet}{C}_6H_6$	—		10	2133	815	38.3
$C_6H_5HgBr + \overset{\bullet}{C}_6H_6$	$CoCl_2$		10	2133	1111	52.1

The results of experiments on the exchange of phenyl radicals in phenylmercury bromide, presented in Table 1, show that the exchange only reached appreciable proportions when certain additives were present, in particular anhydrous cobaltous chloride and silver powder.

In the case of cobaltous chloride, the transfer of activity from $\overset{\bullet}{C}_6H_5Br$ to C_6H_5HgBr was probably caused by the presence of reversible reactions in which the cobaltous chloride acted as a carrier of phenyl radicals from one compound to the other:

$$C_6H_5HgBr + CoCl_2 \rightleftarrows C_6H_5CoCl + HgClBr, \quad C_6H_5CoCl \rightleftarrows C_6H_5 \cdot + CoCl \cdot,$$

$$CoCl \cdot + C_6H_5Br \rightleftarrows C_6H_5 \cdot + CoClBr.$$
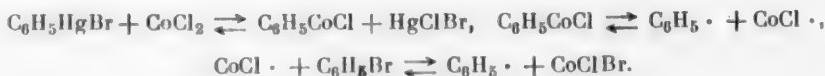
It should be noted that the action of cobaltous chloride appeared more strongly during irradiation with ultraviolet light than with simple heating of the reaction mixture due to the increase in the concentration of phenyl radicals. The accelerating action of silver powder exceeded that of cobaltous chloride (see Table 1), which indicates surface catalysis of the exchange process.

Exchange in the system $C_6H_5HgBr-\overset{\bullet}{C}_6H_6$ proceeded more rapidly than in the system containing $\overset{\bullet}{C}_6H_5Br$, and proceeded to a considerable extent even with simple irradiation with ultraviolet light, which is explained by the easier regeneration of phenyl radicals from $\overset{\bullet}{C}_6H_6$ by the elimination of hydrogen from solvent radicals, formed from the organomercury compound.

To determine the degree of exchange between C_6H_5MgBr and $\overset{\bullet}{C}_6H_5I$ or between C_6H_5MgBr and $\overset{\bullet}{C}_6H_6$, phenylmagnesium bromide in ether solution was carboxylated and the complex formed was decomposed with hydrochloric acid. The benzoic acid liberated by decomposition of the complex was isolated and converted into the sodium salt, which was reconverted into the original acid. The exchange was studied with irradiation by ultraviolet light for a maximum duration of 100 hours and with storage at room temperature for a period of 300 hours. It was established that no exchange of phenyl radicals occurred. As a result of reaction between C_6H_5MgBr and $\overset{\bullet}{C}_6H_5I$, in addition to benzoic acid we isolated diphenyl, whose formation was not detected in the case of the $C_6H_5MgBr-\overset{\bullet}{C}_6H_6$ system. The benzoic acid and diphenyl were analyzed radiochemically. Since the reaction was carried out with excess phenylmagnesium bromide, the process was complete after consumption of all the $\overset{\bullet}{C}_6H_5I$; here, practically all the activity was found in the diphenyl. The addition of ferric chloride or aluminum chloride to the reaction mixture only accelerated decomposition of the organomagnesium compound.

For determining the degree of exchange of ethyl radicals between $\overset{\bullet}{C}_2H_5Br$ and C_2H_5MgBr, the reaction mixture in ether or dimethylaniline was carboxylated with carbon dioxide, the complex decomposed with 20% sulfuric

TABLE 2

Solvent	Experimental conditions	Duration of exp't. (in hours)	Activity (counts/min)		Degree of exchange (in %)
			at 100% exchange	obtained in exp't.	
Ether	UV-radiation	25	577	38	6.6
Ether	20°	36	565	36	6.4
Dimethyl-aniline	20°	36	565	191	34.8

acid and the propionic acid isolated from the mixture, combusted to carbon dioxide and the activity determined. As a result of decomposition of the Grignard complex and ethyl bromide by ultraviolet radiation, gaseous products were formed, and these were mainly ethylene and ethane. Table 2 gives some data on the exchange in this system.

From the experimental data it follows that exchange of ethyl radicals between labeled ethyl bromide and the Grignard complex in ether was insignificant. In dimethylaniline, the degree of exchange was slightly higher, apparently due to the polar character of the solvent, which increased the polarity of the carbon—magnesium bond in ethylmagnesium bromide. Due to the complexity of the structure of the Grignard complex, it is difficult to put forward here any hypothesis on the exchange mechanism.

Exchange of ethyl radicals was not detected in the system $(C_2H_5)_4Pb-\overset{*}{C}_2H_5Br$ on prolonged heating in sealed ampules or on irradiation with ultraviolet light. Radioactive carbon from $\overset{*}{C}_2H_5Br$ passed into gaseous decomposition products. However, if aluminum bromide was added to the system, the amount of decomposed tetraethyllead increased, but part of the radioactive carbon was found in the undecomposed tetraethyllead. Thus, the exchange of ethyl radicals at 150° over a period of 20 hours in the presence of aluminum bromide was about 20%, apparently due to the formation of an intermediate compound facilitating exchange.

To determine the degree of exchange of phenyl radicals between $(C_6H_5)_4PI$ and $\overset{*}{C}_6H_5I$ (or $\overset{*}{C}_6H_6$), to the alcohol solution was added twice the volume of hot water. On cooling, the solution deposited a precipitate of tetraphenylphosphorus iodide, which was then recrystallized. During irradiation with ultraviolet light, or on heating the mixture, only insignificant exchange was observed and this did not exceed the errors of measurement. The introduction of an additive, for example cobaltous chloride or silver powder, had no essential effect on the extent of the exchange, which indicated the low lability of the phenyl radicals in the given system. It was also impossible to detect the exchange of phenyl radicals between $(C_6H_5)_2O$ and $\overset{*}{C}_6H_6$ under treatment with ultraviolet light or on heating. Cobaltous chloride, aluminum chloride, or metallic silver or copper also had no accelerating effect on the exchange. Thus, the results of our experiments agree with literature data [4] on the stability of the bonds of phenyl radicals with oxygen.

The authors are very grateful to G. A. Razuvaev for valuable advice and help.

SUMMARY

A study was made of the exchange of phenyl and ethyl radicals in certain organomercury, organomagnesium, organolead, and organophosphorus compounds. It was shown that the exchange of phenyl radicals in organomercury compounds and of ethyl radicals in organolead compounds proceeds only in the presence of additives, for example, cobaltous chloride, aluminum bromide, and metallic silver. It was established that there was no exchange of phenyl radicals in organomagnesium and organophosphorus compounds, both in the absence of additives and in their presence.

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# PREPARATION OF ASYMMETRIC 2,5-DIARYL DERIVATIVES
OF 1,3,4-OXADIAZOLE

A. P. Grekov and R. S. Azen

All-Union Chemical Reagents Scientific Research Institute, Kharkhov Branch

Original article submitted April 22, 1958

An investigation of the scintillation efficiency of a large number of different organic substances led to the discovery of new and extremely promising classes of compounds, one of which was the oxadiazole class [1-3].

Therefore, to study the relation between structure and scintillation activity in the series of oxadiazole derivatives, and also to look for new highly efficient scintillators, we synthesized asymmetric 2,5-diaryl derivatives of 1,3,4-oxadiazole, previously undescribed in the literature. The corresponding hydrazides, from which these substances were obtained, had not been described either. The following scheme was used for the synthesis of these substances:

$$Ar-\overset{O}{\overset{\|}{C}}-NH-NH_2 \xrightarrow[C_5H_5N]{Ar'COCl} Ar-\overset{O}{\overset{\|}{C}}-NH-NH-\overset{O}{\overset{\|}{C}}-Ar' \xrightarrow{POCl_3} Ar\underset{O}{\overset{N-N}{\diagdown}}Ar',$$

where Ar & Ar' = C_6H_5, 4-$C_6H_4C_6H_5$, 1-$C_{10}H_7$, 2-$C_{10}H_7$.
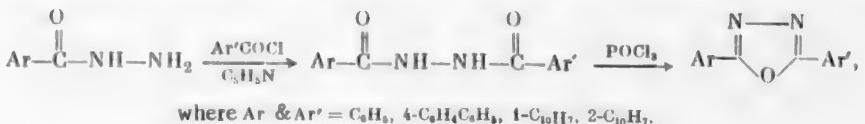
In this scheme, two stages were most interesting from the preparative point of view, and these were the formation of the asymmetric diaryl hydrazide, and ring closure of this hydrazide to give an oxadiazole. In the first case, the formation of the asymmetric hydrazide in pyridine may be complicated by the fact that, for as yet undiscovered reasons, a symmetrical diaryl hydrazide is sometimes obtained together with the main product. In the second case, we established that the formation of the oxadiazole ring required that the appropriate diaryl hydrazide was heated for quite a short time with $POCl_3$, only until the former dissolved completely, since prolonged boiling with phosphorus oxychloride, as is recommended in similar cases, frequently led to a deterioration in the quality of the product obtained.

All the hydrazides obtained in the present work were colorless, crystalline substances, which were readily soluble in pyridine and acetic acid, less soluble in alcohols, benzene and toluene, and insoluble in water and aqueous solutions of mineral acids and alkalies. The corresponding oxadiazoles were colorless compounds, which were readily soluble in the usual organic solvents.

EXPERIMENTAL

Synthesis of 2-(4-Biphenylyl)-5-(1-Naphthyl)-1,3,4-Oxadiazole

1-(4-Biphenylyl)-2-(1-naphthyl) hydrazide. Into a flask fitted with a reflux condenser and a mechanical stirrer was placed 64 g of 1-naphthoyl chloride [4] and 300 ml of dry pyridine, and over a period of 15 minutes, 70 g of 4-biphenylyl hydrazide [5] was then added. The mixture obtained was boiled for 20 minutes, cooled to room temperature, and poured into 1.5 liters of water. The colorless precipitate was collected by filtration, washed with water on the filter, and dried. After recrystallization from acetic acid, the product was obtained in a yield of 102 g (84.3%) and the m.p. was 215°. After several recrystallizations from acetic acid, the product had m.p. 219-220°.

Found %: N 7.57. $C_{24}H_{18}O_2N_2$.

Calculated %: N 7.65.

2-(4-Biphenylyl)-5-(1-naphthyl)-1,3,4-oxadiazole. 58 g of 1-(4-biphenylyl)-2-(1-naphthyl) hydrazide was boiled with 150 ml of POCl₃ for 1 hour, then the bulk of the phosphorus oxychloride was removed by distillation and the residue poured into 0.5 liter of cold water. The colorless crystalline precipitate was collected, washed with water, and dried. After two recrystallizations from glacial acetic acid, the product had m.p. 156-157°, and the yield was 34 g (61.8%).

Found %: N 8.09. $C_{24}H_{16}ON_2$.

Calculated %: N 8.05.

Synthesis of 2-(4-Biphenylyl)-5-(2-Naphthyl)-1,3,4-Oxadiazole

1-(4-Biphenylyl)-2-(2-naphthyl) hydrazide. A mixture of 57 g of 2-naphthyl hydrazide [6] and 60 g of 4-biphenylcarboxyl chloride was dissolved in 360 ml of dry pyridine, boiled for 2 hours, and poured into 3 liters of cold water. A colorless crystalline product with m.p. 200-201° precipitated. After several recrystallizations from acetic acid, the product had m.p. 205-206° and the yield was 43 g (38.5%).

Found %: N 7.61. $C_{24}H_{18}O_2N_2$.

Calculated %: N 7.65.

2-(4-Biphenylyl)-5-(2-naphthyl)-1,3,4-oxadiazole. A mixture of 40 g of 1-(4-biphenylyl)-2-(2-naphthyl) hydrazide and 100 ml of POCl₃ was boiled for 3 hours and then carefully poured onto ice. After 2-3 hours, the precipitate was collected and recrystallized from acetic acid to give 20 g (38%) of product with m.p. 145°.

Found %: N 8.11. $C_{24}H_{16}ON_2$.

Calculated %: N 8.05.

Synthesis of 2-Phenyl-5-(1-Naphthyl)-1,3,4-Oxadiazole

1-Phenyl-2-(1-Naphthyl) hydrazide. 97 g of 1-naphthoyl chloride [4] was mixed with 500 ml of pyridine and to the solution obtained was added 69 g of benzhydrazide [7]. The solution was boiled for 30 minutes and poured into 2 liters of cold water. The reaction product precipitated at first as an oil, which crystallized on cooling to give a colorless crystalline mass with m.p. 146-147° in a yield of 143 g (97%). After several recrystallizations from toluene, the product had m.p. 150.5-151°.

Found %: N 9.76. $C_{18}H_{14}O_2N_2$.

Calculated %: N 9.62.

2-Phenyl-5-(1-naphthyl)-1,3,4-oxadiazole. There is only one mention of this compound in the literature [2], without any details on its synthesis.

70 g of 1-phenyl-2-(1-naphthyl)hydrazide was mixed with 200 ml of POCl₃ and boiled for 1.5 hours. The bulk of the POCl₃ was then removed by distillation and the residue poured into cold water. The precipitated substance was vacuum distilled at 260-265° (6 mm) and then recrystallized from methanol to form colorless crystals with m.p. 117-118° in a yield of 16 g (24.3%). After purification by chromatography on aluminum oxide, the product had m.p. 120° [2].

Synthesis of 2-Phenyl-5-(2-Naphthyl)-1,3,4-Oxadiazole

1-Phenyl-2-(2-naphthyl) hydrazide. 100 g of 2-naphthoyl chloride was dissolved in 700 ml of pyridine and 72 g of benzhydrazide [7] slowly added to the solution obtained, which was then boiled for 30 minutes and poured into 3 liters of water. After recrystallization from dilute acetic acid, the substance had m.p. 194-196°, and the yield was 72 g (47.4%).

Found %: N 9.69. $C_{18}H_{14}O_2N_2$.

Calculated %: N 9.62.

2-Phenyl-5-(2-naphthyl)-1,3,4-oxadiazole. Only the melting point of this substance is given in the literature [2], with no details of its synthesis or properties.

52.6 g of 1-phenyl-2-(2-naphthyl) hydrazide was mixed with 150 ml of $POCl_3$ and boiled for 3 hours. Then 70 ml of $POCl_3$ was removed by distillation and the residue poured into water to give 45 g (91.3%) of product. After recrystallization from methanol and chromatographic purification, the product had m.p. 124° [2].

Synthesis of 2-(1-Naphthyl)-5-(2-Naphthyl)-1,3,4-Oxadiazole

1-(1-Naphthyl)-2-(2-naphthyl) hydrazide. 116 g of 1-naphthyl hydrazide [8] and 115 g of 2-naphthoyl chloride were dissolved in 600 ml of pyridine, and the solution obtained was boiled for 2 hours and then poured into 3 liters of water. The precipitate was recrystallized twice from acetic acid, when the m.p. was 217-218° and the yield 87 g (42%).

Found %: N 8.34. $C_{22}H_{16}O_2N_2$.

Calculated %: N 8.24.

2-(1-Naphthyl)-5-(2-naphthyl)-1,3,4-oxadiazole. A mixture of 87 g of 1-(1-naphthyl)-2-(2-naphthyl) hydrazide and 300 ml of $POCl_3$ was boiled for 5 hours. Then, 150 ml of $POCl_3$ was removed by distillation and the residue poured into water. The precipitated product was recrystallized twice from acetic acid and purified by chromatography to give 46 g (63%) of product with m.p. 136°.

Found %: N 8.85. $C_{22}H_{14}ON_2$.

Calculated %: N 8.70.

SUMMARY

The previously undescribed 2-phenyl-5-(1-naphthyl)-, 2-(4-biphenylyl)-5-(1-naphthyl)-, 2-phenyl-5-(2--naphthyl)-, 2-(4-biphenylyl)-5-(2-naphthyl)-,and 2-(1-naphthyl)-5-(2-naphthyl)-1,3,4-oxadiazoles were synthesized, and also the corresponding hydrazides, from which they were obtained.

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* Original Russian pagination. See C.B. translation.

VIBRATION SPECTRA OF ORGANOPHOSPHORUS COMPOUNDS

A CONTRIBUTION ON THE CHARACTERISTIC NATURE OF THE P = S FREQUENCY

E. M. Popov, T. A. Mastryukova, N. P. Rodionova

and M. I. Kabachnik

Institute of Heteroorganic Compounds, Academy of Sciences, USSR

Original article submitted April 10, 1958

An examination of the vibration spectra of phosphorus and organophosphorus compounds leads to the conclusion that molecules containing the P = O group have a vibration in which this group takes the main part. The slight differences in the frequencies of this vibration in spectra of compounds with different substituents at the phosphorus atom make it possible to consider it quite characteristic in frequency. With rare exceptions, this vibration appears in Raman (R) and infrared (IR) spectra in the region of 1200-1300 cm^{-1}, and serves as a reliable characteristic of the P = O group. For structural and analytical purposes in the chemistry of phosphorus compounds, the spectral characteristics of the P = S group are also of interest.

The vibration spectra of organothiophosphorus compounds have been investigated previously by many authors. Thus, Gore [1] investigated more than 30 IR spectra of organothiophosphorus and organophosphorus compounds. According to his data, the spectrum of $PSCl_3$ has an intense band at 748 cm^{-1}, which is absent from the spectrum of $POCl_3$. The spectra of diethyl chlorothionephosphate and diethyl chlorophosphate differ sharply in the regions of 660 and 1290 cm^{-1}. The presence of a band at 660 cm^{-1} in the spectrum of the first compound, and at 1290 cm^{-1} in that of the second, was explained by the presence of the P = S and P = O bonds. However, in most places it was not possible to link absorption bands in the IR spectra with the thione group of thiophosphorus compounds. The author came to the conclusion that the P = S group did not have a characteristic frequency. Daasch and Smith[2], and Bellamy and Beecher [3], arrived at the same conclusion. In a series of other publications on the IR spectroscopy of thiophosphorus compounds [4-7], no absorption connected with the presence of the P = S bond was identified.

In a monograph on IR spectra of complex molecules, Bellamy [8] came to the conclusion that the absorption mainly associated with the vibration of the P = S bond was in the region of 750-600 cm^{-1} and changed considerably in intensity. Therefore, the absence of noticeable absorption in this region may not be a proof of the absence of the P = S group from the molecule.

In the work of McIvor, Grant and Hubly [9], an investigation was made of the IR spectra of 50 organothiophosphorus compounds, some of which were also examined by us and are presented in the present communication. In this work, the presence of a thione group in the structure of the molecule was linked with frequencies in the region of $835 - 770$ cm^{-1}. However, this conclusion was not confirmed by comparison of the spectra of the thione compounds with those of thiol and oxygen organophosphorus compounds, presented in the article cited. For example, the band at 780 cm^{-1} in the spectrum of CH_3PSCl_2 was assigned to the P = S bond by the authors, but the IR spectrum of CH_3POCl_2 also had a band of the same intensity at 770 cm^{-1}. The spectra of diethyl chlorothionephosphate and diethyl chlorophosphate had absorption bands of similar intensities in the region of 800 cm^{-1}, but the band at 817 cm^{-1} of diethyl chlorothionephosphate was assigned to the thione group. The IR spectra of $(CH_3O)_2PHS$ and $(CH_3O)_2PHO$ showed bands of identical intensity with the frequency of 795 cm^{-1}, but in the article considered, the band at 795 cm^{-1} in dimethyl thiophosphite was assigned to the thione group. In the same way, the rest of the

3000 2000 1500 1000 500

|	
C_2H_5O $P=S$ Cl Cl	1
C_2H_5S $P=O$ Cl Cl	2
CH_3 $P=S$ Cl Cl	3
C_2H_5 $P=S$ Cl Cl	4
C_3H_7 $P=S$ Cl Cl	5
C_2H_5 $P=O$ Cl Cl	6
$(CH_3O)_2P=S$ Cl	7
$(C_2H_5O)_2P=S$ Cl	8
$(C_3H_7O)_2P=S$ Cl	9
$(C_4H_9O)_2P=S$ Cl	10
$(iC_3H_7O)_2P=S$ Cl	11
$(CH_3O)_2P=S$ $NHCH_3$	12
$(C_2H_5O)_2P=S$ $NHCH_3$	13
$(C_3H_7O)_2P=S$ $NHCH_3$	14
$(C_4H_9O)_2P=S$ $NHCH_3$	15
$(iC_3H_7O)_2P=S$ $NHCH_3$	16
$(CH_3)_2N$ $P=S$ Cl Cl	17

Absorption (in %)

100
60
20

3800 2000 1500 1000 500 cm^{-1}
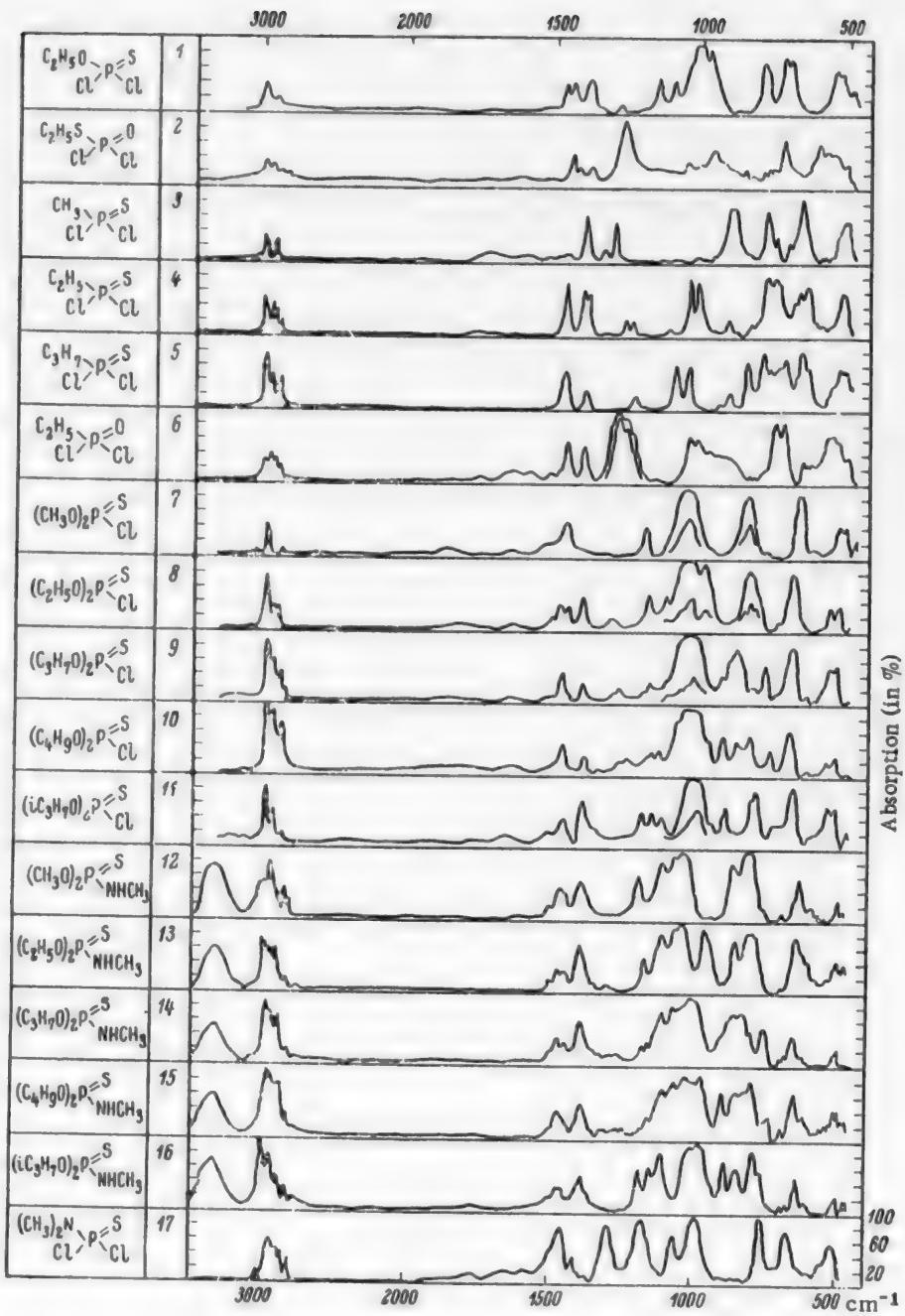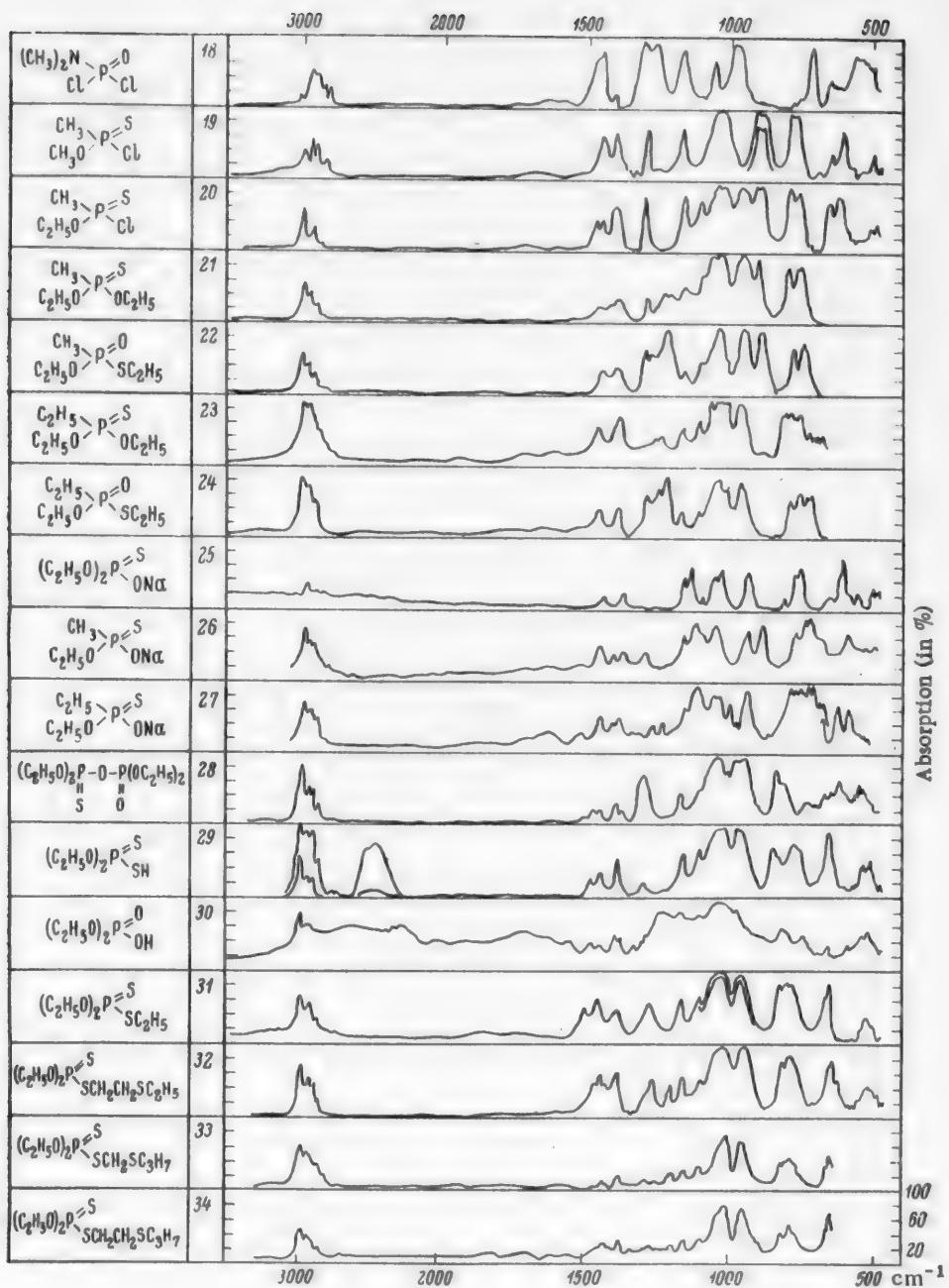
TABLE 1

Raman Spectra*

I. PSCl$_3$: 170 (8), 246 (9), 428 (10), 539 (5), **750 (6)**.

II. C$_2$H$_5$OPSCl$_2$: 146 (1), 193 (10), 242 (7), 391 (4), 431 (2), 469 (7), 486 (7), 556 (1), 697 (5), 722 (5), 779 (0), 1019 (0), 1094 (1), 1385 (0), 1443 (1), 1469 (1), 2901 (0), 2939 (1), 2976 (1), 3012 (0).

III. CH$_3$PSCl$_2$: 128 (1), 185 (10), 262 (10), 346 (1), 393 (2), 427 (3), 448 (10), 505 (4), **666 (7)**, 779 (3), 904 (2), 1393 (3), 2917 (8), 3002 (6).

IV. C$_2$H$_5$POCl$_2$: 161 (1), 198 (2), 217 (2), 271 (0), 288 (2), 338 (4), **381 (5)**, 482 (6), 500 (6), 716 (2), 973 (0), 1031 (1), 1242 (1), **1273 (2)**, 1400 (1), 1455 (1), 2892 (2), 2919 (4), 2951 (4), 3019 (2).

V. (C$_2$H$_5$O)$_2$PSCl: 145 (1), 206 (5), 359 (0), 496 (4), 531 (0), 652 (6), 670 (3), 780 (1), 1096 (4), 1282 (0), 1389 (1), 1444 (2), 1471 (1), 2904 (1), 2938 (7), 2978 (6).

VI. (CH$_3$)$_2$NPSCl$_2$: 145 (1), 174 (4), 226 (2), 250 (4), 313 (1), 371 (8), 387 (2), 428 (0), 508 (10), **673 (6)**, 761 (1), 983 (1), 1437 (2), 1474 (1), 2810 (1), 2854 (2), 2921 (2), 2959 (2), 3010 (1).

VII. (CH$_3$)$_2$NPOCl$_2$: 191 (3), 223 (3), 316 (1), 353 (4), 387 (10), 517 (7), 722 (3), **1261 (4)**, 1442 (2), 1477 (1), 2820 (1), 2863 (2), 2935 (2), 2956 (2), 3017 (1).

VIII. (C$_2$H$_5$O)$_3$P=S: 143 (2), **608 (5)**, **635 (2)**, 780 (1), 943 (1), 1023 (1), 1098 (4), 1280 (2), 1389 (0), 1447 (3), 1474 (1), 2904 (2), 2936 (7), 2979 (5).

IX. (C$_2$H$_5$O)$_2$PO(SC$_2$H$_5$): 146 (1), 289 (2), 392 (1), 562 (2), 602 (2), **646 (6)**, 747 (2), 798 (1), 968 (0), 1052 (2), 1095 (4), **1244 (3)**, 1281 (1), 1446 (4), 1471 (1), 2904 (1), 2935 (8), 2977 (6).

X. (C$_2$H$_5$O)$_3$P=O: 144 (1), 723 (2), 741 (2), 814 (1), 1029 (1), 1099 (4), 1267 (2), **1288 (3)**, 1384 (1), 1445 (4), 1473 (1), 2906 (4), 2936 (7), 2981 (6).

XI. (C$_2$H$_5$S)$_2$POCl: 144 (1), 176 (2), 234 (3), 288 (1), 458 (7), 466 (7), 536 (1), 578 (1), **635 (6)**, 965 (1), 1053 (2), **1227 (4)**, 1422 (1), 1448 (2), 2936 (7), 2973 (4).

XII. (C$_2$H$_5$O)$_2$C$_2$H$_5$PS: 144 (1), 326 (1), **584 (6)**, 606 (1), 1038 (0), 1093 (4), 1284 (1), 1400 (1), 1452 (4), 2905 (2), 2938 (7), 2983 (5).

XIII. (C$_2$H$_5$O)C$_2$H$_5$PO(SC$_2$H$_5$): 142 (1), 278 (2), 481 (0), 521 (2), 565 (1), **647 (4)**, 698 (1), 774 (0), 962 (0), 1040 (1), 1092 (2), **1210 (3)**, 1273 (0), 1401 (1), 1448 (4), 2916 (1), 2935 (7), 2977 (5).

XIV. (C$_2$H$_5$O)$_2$C$_2$H$_5$PO: 145 (1), 694 (3), 737 (1), 811 (0), 1037 (1), 1096 (3), **1225 (3)**, 1337 (2), 1402 (1), 1451 (4), 2908 (2), 2936 (7), 2980 (5).

XV. (C$_2$H$_5$O)$_2$PS(OCH$_2$CH$_2$SC$_2$H$_5$): 143 (1), **607 (5)**, **651 (3)**, 687 (4), 746 (3), 850 (0), 951 (0), 1042 (0), 1108 (3), 1282 (3), 1447 (4), 2902 (1), 2933 (7), 2977 (5).

XVI. (C$_2$H$_5$O)$_2$PO(SCH$_2$CH$_2$SC$_2$H$_5$): 145 (1), **651 (3)**, 688 (4), 745 (4), 849 (0), 1048 (1), 1095 (3), **1249 (3)**, 1278 (3), 1448 (4), 2903 (1), 2931 (7), 2976 (5).

XVII. (C$_2$H$_5$O)$_2$PSSH: 145 (1), 192 (2), 350 (2), 504 (4), 534 (3), **653 (7)**, 764 (3), 1097 (4), 1281 (1), 1384 (0), 1445 (3), 2543 (2b**), 2897 (1), 2934 (6), 2974 (4).

XVIII. (C$_2$H$_5$O)$_2$PS(SC$_2$H$_5$): 144 (1), 224 (2), 518 (1), 546 (1), **654 (7 b)**, 1050 (1), 1095 (3), 1285 (1), 1387 (1), 1444 (4), 2900 (2), 2932 (7), 2971 (5).

XIX. (C$_2$H$_5$O)$_2$PS(SCH$_2$CH$_2$SC$_2$H$_5$): 145 (1), **652 (6 b)**, 689 (3), 750 (3), 1003 (0), 1045 (0), 1093 (2), 1277 (2), 1445 (3), 2903 (1), 2928 (7), 2972 (5).

XX. (C$_2$H$_5$O)$_2$PHS: 144 (1), **633 (5)**, 651 (2), 762 (1), 1096 (2), 1279 (1), 1445 (3), 2467 (3 b), 2902 (1), 2936 (6), 2980 (4).

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* The frequencies selected refer to the P=S, P=O, P—SC$_2$H$_5$ and CH$_2$CH$_2$SC$_2$H$_5$ groups.

** b = broad.

assignments made by McIvor, Grant and Hubly are doubtful. The frequencies ascribed by the authors to the P = S group changed noticeably when the alkyl radicals in the substituents were changed; on the other hand, they often coincided for organothiophosphorus compounds of completely different types. It can also be recorded that these frequencies did not appear, or had very insignificant intensities in the R spectra we obtained. This also disagrees with the assignments of these authors, especially if we consider the multiple character of the P = S bond.

Up to the present time, the R spectra of thiophosphorus compounds have only been investigated in single cases [10-15], and simple molecules were dealt with mainly. There is no theoretical work in the literature on calculation of the normal vibrations of the molecules of organothiophosphorus compounds.

There are considerable grounds for assuming that the frequencies connected with the presence of a P = S group in a molecule must change with a change in the nearest surroundings of the phosphorus atom to a considerably greater extent than the frequencies of the P = O bond. It seems to us that precisely this circumstance was not considered by the authors of the articles cited, and this led to incorrect conclusions on the characteristic frequencies of the thione group.

In order to find the so-called characteristic frequencies of the P = S group, we obtained the IR and R spectra of organic thionephosphorus compounds, parallel with the corresponding thiolphosphorus and phosphorus compounds.

The IR absorption spectra presented in the figure in the present work (1-34) were obtained on a single-beam Perkin-Elmer 12B spectrophotometer with photographic recording, using sodium chloride, lithium fluoride and, in some cases, potassium bromide prisms. The substances were placed between two sylvite plates; in all cases, the layer thickness was approximately the same, and about 0.01 mm. Preparations of the sodium salts of thiophosphoroorganic acids were made up in the form of a paste by carefully mixing the salts with vaseline oil. In regions where the vaseline oil absorbed similarly, the solid substances were used after evaporation of suspensions of them in carbon tetrachloride.

The R spectra were obtained on an ISP-51 spectrograph with excitation by the mercury line at 4358 A, which was separated with a glass filter; the linear dispersion of the spectrograph with a camera with $f = 270$ mm was 25 A/mm in the region of blue lines. The width of the slit image on the spectrum was 5 cm^{-1}. The exposure was 6 hours. Before the spectrum was plotted, the freshly distilled substances were further distilled in vacuum bulbs and placed in a cell 10 mm long and 8 mm in diameter. The intensity of the lines was evaluated visually with respect to a scale of ten. All the compounds, whose spectra are presented in the present work, were used in a freshly vacuum distilled state.

As reported above, the IR and R spectra of $PSCl_3$ (I)* had a band with a maximum at 748 cm^{-1}, which pertained to vibration of the P = S bond. When one chlorine atom was replaced by an ethoxy group (see $C_2H_5OPSCl_2$)(1) the IR spectra in this region showed three bands: 795, 725, and 700 cm^{-1}. The bands at 795 and 700 cm^{-1} were absent from the spectrum of the thiol isomer (2). According to many data [16, 17, 2], the frequency of 795 cm^{-1} is connected with vibrations of the P—OR group (R is alkyl). Thus, we are left with the hypothesis that the band at 700 cm^{-1} is caused by the presence of the P = S bond in the molecule of ethyl dichlorothionephosphate. The IR spectrum of methyl dichlorothionephosphate [9] also has a band at 700 cm^{-1}. The line at 697 cm^{-1} in the R spectrum of $C_2H_5OPSCl_2$ (II) (Table 1), evidently, may be accepted as the P = S frequency. The IR spectrum of CH_3PSCl_2 (3) had a band at 664 cm^{-1}, and the spectra of $C_2H_5PSCl_2$ and $C_3H_7PSCl_2$ (4,5) had the triplet bands 680, 665, 640 and 675, 660, and 635 cm^{-1}, respectively, evidently caused by the presence of P = S groups in these molecules. In the spectra of CH_3POCl_2 (21) and $C_2H_5POCl_2$ (6), the absorption in this region is considerably weakened and intense bands appear at 1285 cm^{-1}, in the spectrum of the former, and at 1285 and 1265 cm^{-1}, in the spectrum of the second, which are connected with the P = O group. The triplet character of the P = S bands in the spectra of $C_2H_5PSCl_2$ and $C_3H_7PSCl_2$ is possibly connected with the realization of several conformations of these molecules; evidently, the P = O band in the spectrum of $C_2H_5POCl_2$ has a complex character for the same reason. The spectra of CH_3PSCl_2 and CH_3POCl_2, where rotation isomerism of this type is excluded, show only single bands connected with the P = S and P = O groups.

In the R spectra of CH_3PSCl_2 (III) and $C_2H_5POCl_2$ (IV), the frequency 666 cm^{-1} in spectrum (III) and 1273 cm^{-1} in spectrum (IV) are the P = S and P = O frequencies, respectively.

The spectra of dialkyl chlorothiophosphates and dialkyl chlorophosphates differ markedly in the regions of 1300 and 660 cm^{-1}. The spectra of the five thione derivatives, $(RO)_2PSCl$, where R=CH_3, C_2H_5, C_3H_7, C_4H_9, and iso-C_3H_7 (7-11), investigated, show intense absorption bands at 660, 665, 667, and 656 cm^{-1}, respectively. The R spectrum of $(C_2H_5O)_2PSCl$ (V) has a line at 652 cm^{-1}. According to the data of Gore [1] (IR spectrum) and of Baudler [17] (R spectrum) dialkyl chlorophosphates do not have bands in this region, and others appear at 1290 cm^{-1}. Since this only occurs when the P = S group is replaced by P = O while the rest of the structure of the molecule is retained, we assign the region of $665 - 652$ cm^{-1} to the P = S frequencies in this class of compound.

On replacement of the chlorine atom in dialkyl chlorothiophosphates by the NHCH$_3$ group (12-16), a shift is observed in the absorption band at 660 cm^{-1} of approximately 20 cm^{-1} toward longer wavelengths for all five of the compounds investigated (633, 638, 645, 645, and 637 cm^{-1}, respectively, for compounds with R = CH_3, C_2H_5, C_3H_7, C_4H_9, and iso-C_3H_7). It is quite probable that absorption in the region of 640 cm^{-1} is connected with the presence of the P = S bond in the molecules, $(RO)_2PSNHCH_3$, where R is an alkyl radical.

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*The numbers of the infrared spectra are given in Arabic numerals, the numbers of the Raman spectra in Roman numerals.

A comparison of the IR spectra (17, 18) and the R spectra (VI, VII) of dimethylamidodichlorothiophosphate and dimethylamidodichlorophosphate makes it possible to assign the band at 670 cm^{-1} (673 cm^{-1} in the R spectrum) in the spectra of the thione derivative to the P = S group.

In the IR spectra of the acid chlorides of the methyl and ethyl esters of methylthionephosphinic acid (19,20) and in the spectrum of the isopropyl ester of methylthionephosphinic acid [9], there were bands at 620, 625, and 629 cm^{-1} in the region of P = S frequencies, which probably belong to the latter.

Vibration spectra of trialkyl thionephosphates were presented in the works of Gore [1], Daasch and Smith [2] and others [14, 15]. There were absorption bands in the region of P = S frequencies in the IR spectra of trimethyl and triethyl thionephosphate, and also in the spectra of the corresponding thiol compounds and, therefore, it is very difficult to make unequivocal assignments on the basis of infrared spectra alone. The R spectrum of triethyl thionephosphate (VIII) showed lines at 608 and 635 cm^{-1}. The R spectra of triethyl phosphate had lines of only very low intensity in the region 700-500 cm^{-1} (X). Triethyl thiolphosphate (IX) had a line at 646 cm^{-1} (X), which was detected in the R spectra of other compounds containing the P−SR group. For example, the P = S bond is absent from the molecule of diethyl diethylchlorodithiolphosphate (XI), but due to the presence of the P−SC$_2$H$_5$ group, the R spectrum contained an intense line at 635 cm^{-1}.

In the spectra of sulfur-containing derivatives of phosphinic acids (XII, XIII, and XIV), the picture observed was similar to that observed in the spectra of phosphoric acid derivatives. The spectrum of the diethyl ester of ethylthionephosphinic acid had lines at 584 and 606 cm^{-1} (XII). The diethyl ester of ethylphosphinic acid (XIV) had no lines in the region of 690-500 cm^{-1}, while the spectrum of the diethyl ester of ethylthiolphosphinic acid (XIII) had a line at practically the same frequency (647 cm^{-1}) as that of triethyl thiolphosphate, and connected with the P−SC$_2$H$_5$ group. The IR spectra of the phosphinic compounds were obtained only with prisms of sodium chloride and lithium fluoride and, therefore, we were unable to observe the P = S frequencies, which lay beyond the limits of the region of the sodium chloride prism. However, the thiol and thione isomers (21-24) of these compounds were also readily distinguished in the region of 1200 cm^{-1}, where the thiol isomers had intense doublet bands corresponding to the P = O bond. The doublet character of the P = S and P = O bands in the spectra of these compounds is probably connected with the presence of rotation isomers.

Thus, it may be assumed that with trialkyl thionephosphates, frequencies in the region of 610 cm^{-1} may be assigned to the P = S group, and with esters of alkylphosphinic acids, frequencies in the region of 580 cm^{-1}. It is interesting to note that the spectrum of sodium diethylthiophosphate (25) showed a band at 606 cm^{-1}; according to the data of Gore [1], the spectrum of the potassium salt also has a band in this region. The spectra of the sodium salts of the ethyl esters of methyl- and ethylthiophosphinic acids (26, 27) had bands at 584 and 578 cm^{-1}. These bands are probably connected with the thione structure of these salts.

The frequency of the P = S bond of tetraethyl thionepyrophosphate also remained practically constant. It equalled 606 cm^{-1} (28) in the IR spectrum and 609 cm^{-1} in the R spectra [15]. Bands were not observed in this region in the vibration spectra of the corresponding oxygen pyrophosphates.

Henglein, Schrader and Muhlman [5] investigated the IR spectra of diethyl-O-ethylmercaptoethylthionephosphate and its thiol isomer in the NaCl region. The authors found an essential difference in the spectra only in the region of 1255 cm^{-1}, where there was intense absorption in the case of the compound with the P = O group, and there was no appreciable absorption in this region in the case of the P = S group. We obtained the R spectra of these substances (XV, XVI) and found that the thione isomer had lines at 607 and 651 cm^{-1} in the region interesting us, and the thiol isomer had a line at 651 cm^{-1} only. Evidently, the line at 607 cm^{-1} may be assigned confidently to the P = S bond, as, first, it is absent from the spectrum of the isomer and, second, it agrees in frequency with the P = S frequencies of trialkyl thionephosphates with the same nearest surroundings at the phosphorus atom. The line at 651 cm^{-1} probably belongs to the −CH$_2$CH$_2$SC$_2$H$_5$ group. In the region of the P = O frequencies, the R spectra also showed a difference analogous to that in the IR spectra: the thiol isomer had a line at 1249 cm^{-1}, which was absent from the spectra of the thione isomer.

Vibration spectra of organodithiophosphorus compounds. The IR spectrum of diethylthionethiolphosphoric (29) and dimethylthionethiolphosphoric acid [9] showed intense bands with a frequency of 654 cm^{-1} and the R spectrum, at 653 cm^{-1} (XVII), which were absent from the spectra of diethylphosphoric acid (30) and, according to the data of Daasch and Smith [2], from the spectrum of methylethylphosphoric acid. It is extremely probable that the band at 654 cm^{-1} is caused by the presence of the P = S group in this molecule.

TABLE 2

Vibration Frequencies of the P = S Group in Various Types of
Thiophosphorus Compounds

Type of compound	Frequency, cm^{-1}	Type of compound	Frequency, cm^{-1}
Cl, Cl→P=S, Cl	750	RO, RO→P=S, R	580
Cl, Cl→P=S, RO	700	Cl, Cl→P=S, R$_2$N	670
Cl, RO→P=S, RO	660	RO, RO→P=S, RHN	640
RO, RO→P=S, RO	610	RO, RO→P=S, HS	650
Cl, Cl→P=S, R	665	RO, RO→P=S, RS	660
Cl, RO→P=S, R	620	RO, RO→P=S, H	630
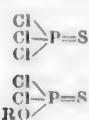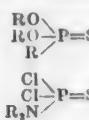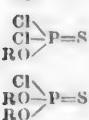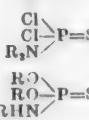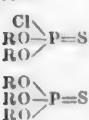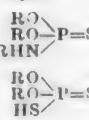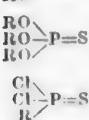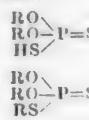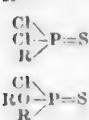
Other dithiophosphates, whose molecules contained the skeleton $\begin{smallmatrix} O \\ O \end{smallmatrix} P \begin{smallmatrix} S \\ S-C \end{smallmatrix}$, had intense bands in this re-
gion both in the IR and in the R spectra, but the character of these bands was more complex. Thus, the IR spectra
of triethyl thionethiolphosphate (31) and trimethyl thionethiolphosphate [9] contained doublet bands at 655 and
666 cm^{-1} and the R spectrum of triethyl thionethiolphosphate (XVIII) had a broad, intense line at 654 cm^{-1}; the
IR spectrum of O,O-diethyl-S-ethylmercaptoethyl dithiophosphate (32) had lines at 651 and 660 cm^{-1}, and the
R spectrum (XIX) at 652 cm^{-1}. The IR spectra of compounds (33 and 34) showed bands at 665, 667, and 656 and
669 cm^{-1}, respectively. It seems to us that the presence of the doublet bands may be explained by the closeness
of the frequencies connected largely with the P = S and P−SC$_2$H$_5$ or P−SCH$_2$CH$_2$SC$_2$H$_5$ groups. For example, in
the spectra of the thiolphosphorus compounds investigated, the P−SR frequencies were in the region of 635-654 cm^{-1}
and the same region contained the P=S frequencies of the dithiophosphates (spectra of dialkyldithiophosphoric
acids). In assigning substances to the thiol or thione series by means of vibration spectra, it is necessary to con-
sider the possibility of the appearance of intense bands in the region of P = S frequencies, but connected with the
presence of the P−SR group.

Let us examine the R spectrum of diethyl thiophosphite (XX). The spectrum has lines at 2407 and 633 cm^{-1},
where the first is the characteristic frequency of the P = H bond [8, 16], and the second line evidently belongs to
the P = S bond, since no bands are present in this region in the spectra of dialkyl phosphites [8]. In the IR spectra
of dimethyl and diethyl thiophosphite, presented in the work of McIvor, Grant and Hubly [9], there are bands
with the frequency of 636 cm^{-1}, which are absent with the compounds (RO)$_2$POH, where R = CH$_3$, C$_2$H$_5$, n-C$_3$H$_7$,
iso-C$_3$H$_7$, and n-C$_4$H$_9$.

SUMMARY

The compounds investigated showed bands, connected with the P = S group, in the region 750-580 cm^{-1}.
The frequency of the normal molecular vibration, in which the P = S group participates, was very liable to con-
stitutive effects, in which each type of substituent changed the frequency by a definite value. The frequencies
ascribed to the P = S group (Table 2) only retain constant values when the nearest surroundings of the central
phosphorus atom remain the same.

Bonds and angles, not having a common atom with the P = S group, played little part in the given vibration
and hardly affected the frequency. We will make the final conclusion in this respect after calculation of the

normal vibrations of the molecules, the quantitative determination of the characteristics of this vibration with respect to frequency and form, and a numerical analysis of the dependence of frequency on the force and kinematic parameters of the molecule on the basis of the theory of characteristic frequencies [18].

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INTERACTION OF NITROSYL CHLORIDE WITH UNSATURATED HYDROCARBONS

VI. REACTION WITH α-METHYLSTYRENE

K. A. Ogloblin and V. P. Semenov

Leningrad State University

Original article submitted May 12, 1958

It was previously stated [1] that little consideration has been given in the literature to the problem of the reaction of nitrosyl chloride with mono- and unsymmetrical disubstituted ethylenes. In order to broaden our ideas on the effect of substituents at the ethylene bond on the direction of this reaction, an investigation was made of the interaction of nitrosyl chloride with α-methylstyrene.

As in previous investigations [1], the reaction was carried out in ether solution with equimolecular amounts of reagents or with a slight excess of nitrosyl chloride, and at a ratio of 3-4 ml of ether to 1 g of NOCl. The reaction products, which were a green liquid with lachrimatory properties, yielded a mixture of two unsaturated monochlorides, which could not be separated by distillation, namely 1-chloro-2-phenylpropene-1 (I) and 1-chloro--2-phenylpropene-2 (II), and also 1,2-dichloro-2-phenylpropane (III) and 1-nitro-2-phenylpropene-1 (IV). The presence of acetophenone in several narrow fractions was demonstrated.

The bulk of the reaction products was formed by the mono- and dihalogen derivatives (I), (II), and (III), which indicates the predominance of the chlorinating action of nitrosyl chloride on α-methylstyrene.

1-Chloro-2-phenylpropene-1 (I) was most probably obtained as a result of the elimination of hydrogen chloride from (III) and (II), by chlorination of α-methylstyrene according to the L'vov-Tishchenko scheme [2]:

$$C_6H_5-C=CH_2 \xrightarrow{Cl_2(NOCl)} \begin{array}{l} C_6H_5-CCl-CH_2Cl \xrightarrow{-HCl} C_6H_5-C=CHCl \\ \quad\quad | \quad\quad\quad\quad\quad\quad\quad\quad\quad | \\ \quad\quad CH_3 \text{ (III)} \quad\quad\quad\quad\quad CH_3 \text{ (I)} \\ \\ C_6H_5-C-CH_2Cl \\ \quad\quad \| \\ \quad\quad CH_2 \text{ (II)} \end{array}$$
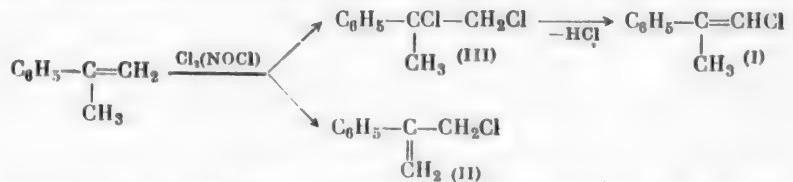
After many unsuccessful attempts to separate individual monochlorides from the mixture by distillation, we ozonized the fraction containing the monochlorides. Among the ozonolysis products we found hydrogen chloride, formaldehyde, formic acid, acetophenone, and chloroacetophenone:

$$\begin{array}{l} C_6H_5-C=CHCl \\ \quad\quad | \\ \quad\quad CH_3 \\ \\ C_6H_5-C-CH_2Cl \\ \quad\quad \| \\ \quad\quad CH_2 \end{array} \xrightarrow{O_3} \begin{array}{l} C_6H_5-CO-CH_3 + HCl + CO \\ \\ C_6H_5-CO-CH_2Cl + HCHO + HCOOH \end{array}$$
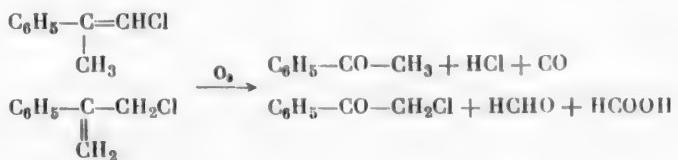
We obtained slightly less chloroacetophenone than acetophenone and, consequently, the mixture of chlorides contained slightly less of the allyl chloride (II) than of (I). Calculation of the amount of allyl chloride (II) in the mixture from the amounts of formaldehyde and formic acid found gave a content of 43% (II) in the mixture.

Similar results were obtained by hydrolysis of the monochloride fraction with alcoholic alkali. When the mixture of monochlorides was heated with 0.1 N alcohol solution of KOH for 1.5 hours, 45% of the total chlorine was hydrolyzed, i.e.,the amount of chlorine corresponding to the allyl chloride (II) content of the mixture.

The formation of (IV) may be explained in the following way. The first reaction product, the nitrosochloride (V), was oxidized by nitrosyl chloride to 2-chloro-1-nitro-2-phenylpropane (VI). Compound (VI) contained a very labile chlorine atom and readily lost hydrogen chloride on distillation of the reaction products.

$$C_6H_5-\underset{\underset{CH_3}{|}}{C}=CH_2 \xrightarrow{NOCl} \left[C_6H_5-\underset{\underset{CH_3}{|}}{C}(Cl)-CH_2NO \right] \xrightarrow{NOCl} \left[C_6H_5-\underset{\underset{CH_3}{|}}{C}(Cl)-CH_2NO_2 \right] \longrightarrow$$

$$\xrightarrow{-HCl} C_6H_5-\underset{\underset{CH_3}{|}}{C}=CHNO_2$$

(V) (VI) (IV)
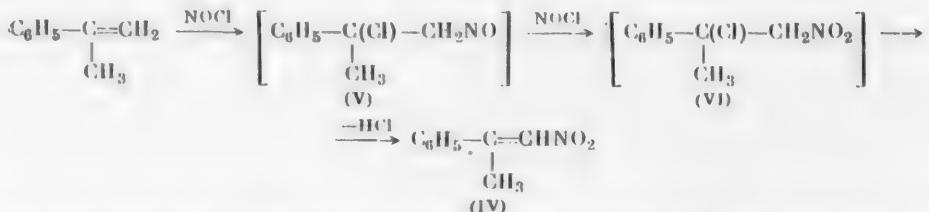
It is known [3] that when heated in the presence of water, nitroolefins may be hydrolyzed to carbonyl compounds. It is extremely probable that the occurrence of acetophenone in the reaction products was caused by hydrolysis of (IV) during distillation.

$$C_6H_5-\underset{\underset{CH_3}{|}}{C}=CHNO_2 \xrightarrow{H_2O} C_6H_5COCH_3 + CH_3NO_2$$
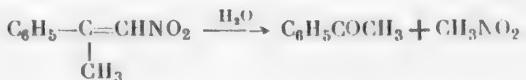
According to Priebs [3], phenylchloroacetic acid is obtained when β -nitrostyrene is heated with hydrochloric acid. Under these conditions, 2-chloro-2-phenylpropionic acid should be obtained from (IV). The products of the reaction of (IV) with hydrochloric acid yielded an acid whose melting point and neutralization equivalent were close to those expected for 2-chloro-2-phenylpropionic acid.

Hydrogenation of (IV) on a palladium catalyst gave 1-nitro-2-phenylpropane. Hydrogenation on Raney nickel catalyst, and also reduction with zinc amalgam, was accompanied by elimination of the nitro group.

In conclusion, mention should be made of the determining effect of the experimental conditions on the direction of the reaction. While under our conditions the main reaction products were chlorination products of α-methylstyrene, which did not contain nitrogen, and the crystalline nitrosochloride was not formed at all, the latter was the main product if the reaction with α-methylstyrene was carried out without solvent, and the nitrosyl chloride was prepared in the reaction sphere from amyl nitrite and hydrochloric acid [5].

EXPERIMENTAL

α-Methylstyrene. Crude dimethylphenylcarbinol, obtained by a Grignard reaction from phenylmagnesium bromide and acetone, was distilled at normal pressure in the presence of iodine. The hydrocarbon was separated from the water, washed with hydrosulfate solution and water, dried with baked potassium carbonate,and vacuum distilled on a column of 12 theoretical plates. A fraction of α-methylstyrene was collected with b.p. 65-66° at 23 mm, and d^{20}_4 0.9131 and $n^{20}D$ 1.5357. According to data in [6], the b.p. is 161.6° at 760 mm, d^{20}_4 0.9096, and $n^{20}D$ 1.5363.

Nitrosyl chloride was obtained by the reaction of a saturated solution of sodium nitrite with concentrated hydrochloric acid [7], heated to boiling for 30-40 minutes under a reflux condenser cooled with solid carbon dioxide and alcohol (−40 to −50°), and then distilled.

Interaction of α-methylstyrene with nitrosyl chloride. To a stirred mixture of 243 g (2.06 mole) of hydrocarbon and 170 ml of dry ether, cooled to −16°, was added a solution of 145 g (2.21 mole) of nitrosyl chloride in 250 ml of dry ether, cooled with a mixture of ice and salt, over a period of 50 minutes. The temperature of the reaction mixture rose to −10° during this, rose to +8° after a further 15 minutes, and then fell to −14° in the subsequent 35 minutes. The reaction mixture was left overnight. The next day, the reaction products were an intense green liquid with a sharp lachrimatory smell. The ether solution of the reaction products was washed several times with water and dried with calcium chloride, the ether removed on a water bath, and the residue vacuum

distilled from a flask with a small fractionating head, at first on a water and then on a metal bath. At the end of the distillation, we observed partial decomposition of the substance with the liberation of hydrogen chloride, which was accompanied by some increase in pressure in the apparatus. A total of 135 g of reaction products distilled and a dark viscous tar remained.

As a result of many vacuum distillations on a column of 12 theoretical plates, fractions with the following boiling points were obtained: 1st in the range 31-55° at 4mm, 12.8 g; 2nd, 48-57° at 3 mm, 8.7 g; 3rd, a series of fractions in the range 57-61° at 3 mm, a total of 20.0 g; 4th, 61-63° at 3 mm, 12.5 g; 5th, 63-65° at 3 mm, 10.9 g; 6th, 65-81.5° at 3 mm, 4.3 g; 7th, 81.5-82.0° at 3 mm, 5.7 g; 8th, 93-115° at 4 mm, 5.9 g; 9th, 115 to 121° at 4 mm, 6.1 g; 10th, 121-123° at 4 mm, 8.6 g.

Investigation of Reaction Products

1st fraction: the bulk of the substance boiled below 34° at 4 mm. The colorless liquid with the smell of α-methylstyrene did not contain chlorine, decolorized a solution of potassium permanganate, and contained a small amount of a carbonyl compound (small precipitate with 2,4-dinitrophenylhydrazine). The fraction was α-methylstyrene with a small amount of acetophenone.

2nd fraction: the colorless liquid with a slightly lachrimatory smell contained chlorine and a carbonyl group. With a solution of semicarbazide it gave a precipitate of a semicarbazone with m.p. 194-194.3° (from water). A mixed melting point with the semicarbazone of acetophenone (m.p. 198° [8]) was not depressed. A quantitative determination of the carbonyl compound in the fraction by the oximation method [9] indicated 22.55 and 22.59% of acetophenone. Analysis for the chlorine content showed that the fraction contained 78% of monochlorides, calculated on the formula C_9H_9Cl.

Found %: Cl 18.10, 18.18.[*] C_9H_9Cl.

Calculated %: Cl 23.30.

The fraction was a mixture of monochlorides, C_9H_9Cl, with acetophenone.

The 3rd fraction had $n^{20}D$ from 1.5421 to 1.5567. The substance contained chlorine and a carbonyl group. The fraction yielded a 2,4-dinitrophenylhydrazone with m.p. 244.5-245°, a mixture of which, with the authentic 2,4-dinitrophenylhydrazone of acetophenone (m.p. 249° [8]), melted without depression.

The fraction was a mixture of monochlorides, C_9H_9Cl, with acetophenone.

4th fraction: $n^{20}D$ 1.5612-1.5624. This was a mixture of monochlorides with an insignificant amount of low-boiling fractions (see fraction 5).

The 5th fraction was a yellowish green liquid with a sharp lachrimatory smell, was insoluble in water, and decolorized a carbon tetrachloride solution of bromine.

d^{20}_4 1.0901, $n^{20}D$ 1.5628, MR_D 45.46; calc. 44.66.

Found %: Cl 23.09, 23.22. C_9H_9Cl.

Calculated %: Cl 23.30.

Ozonization of 5th fraction. A solution of 6 g of material in 27 ml of chloroform, cooled to −15°, absorbed 2.014 g of ozone in 4 hours; one double bond required 1.895 g of ozone.

After removal of the chloroform in vacuum, the ozonides were decomposed, at first in the cold and then with heating. The oily layer, combined with ether extracts from the aqueous layer, yielded the following fractions: a) b.p. up to 58° at 4 mm, 0.4 g, $n^{20}D$ 1.5335; b) 58-59° at 4 mm, 1.0 g, $n^{20}D$ 1.5350; c) 96° at 4 mm, 1.4 g. The last fraction rapidly crystallized and had m.p. 49-50°.

Fractions a and b were colorless liquids, containing traces of chlorine, and gave reactions for a carbonyl group. Fraction a yielded a semicarbazone with m.p. 195-196° (from water), undepressed by admixture with authentic acetophenone semicarbazone. Fraction b yielded a 2,4-dinitrophenylhydrazone with m.p. 230-231° (from glacial acetic acid). A mixture with authentic acetophenone 2,4-dinitrophenylhydrazone melted at 238 to 239°.

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[*]All the chlorine analyses were carried out by Korshun's method.

Fraction c formed white crystals with a sharp, lachrimatory smell. The substance contained chlorine and a carbonyl group. The 2,4-dinitrophenylhydrazone formed fine brown crystals with m.p. 205.5-206.5° (with decomp.).

Found %: N 17.03, 16.52. $C_{14}H_{11}O_4N_4Cl$.

Calculated %: N 16.74.

The substance was chloroacetophenone. According to data in [10], the b.p. is 140° at 15 mm, the m.p. 60°, and the 2,4-dinitrophenylhydrazone has m.p. 212°.

The aqueous layer of the ozonization products contained ionic chlorine, formaldehyde, and formic acid. The solution was found to contain 0.107 g of formaldehyde, which formed a dimedone derivative with m.p. 192 to 192.5° (from alcohol), and a mixture of this with authentic dimedone derivative of formaldehyde melted at 191-192°.

The amount of formaldehyde and formic acid corresponds to the mixture containing 2.58 g (43%) of the allyl chloride, 1-chloro-2-phenylpropene-2 (0.55 g from the formaldehyde and 2.03 g from the formic acid).

The results of ozonization show that the fraction with b.p. 63-65° at 3 mm was a mixture of 1-chloro-2-phenylpropene-1 (I) and 1-chloro-2-phenylpropene-2 (II).

According to data in [11], 1-chloro-2-phenylpropene-2 has b.p. 87-88° at 5 mm, d^{20}_4 1.0820, n^{20}D 1.5550; according to data in [10], 1-chloro-2-phenylpropene-1 has b.p. 102-106° at 14 mm.

Hydrogenation of 5th fraction. When 3 g of substance was hydrogenated in 50 ml of alcohol over a palladium catalyst, the hydrogenation rate fell by a factor of two and began to decrease rapidly when 415 ml of hydrogen had been absorbed (one double bond requires 440 ml). A total of 588 ml of hydrogen (0°, 760 mm) was absorbed. The alcohol solution yielded 0.7 g of isopropylbenzene:

d^{20}_4 0.8683, n^{20}D 1.4932, MR$_D$ 40.24; calc. 40.38. According to [12], d^{20}_4 0.8640, n^{20}D 1.4932.

The 6th fraction was a mixture of monochlorides and dichloride.

The 7th fraction was a colorless, transparent liquid, which darkened on storage and was insoluble in water. During distillation of a preparation that had been stored for a long period, the presence of lower-boiling products (66-70° at 3 mm), and the evolution of hydrogen chloride were always observed.

d^{20}_4 1.1843, n^{20}D 1.5457, MR$_D$ 50.58; calc. 49.94.

Found %: Cl 34.36, 34.62. $C_9H_{10}Cl_2$.

Calculated %: Cl 37.50.

In another experiment, a dichloride fraction with b.p. 70-72° at 2 mm was isolated.

d^{20}_4 1.1824, n^{20}D 1.5470.

Found %: Cl 37.21, 37.10. $C_9H_{10}Cl_2$.

Calculated %: Cl 37.50.

A sample of the material was hydrolyzed in the presence of barium carbonate, and prolonged extraction of the aqueous layer of reaction products yielded a small amount of an oil which did not contain chlorine, and which partially crystallized. After being dried on a porous plate, the crystals melted at 47-49°. The nature of the oil could not be established. According to [13], 2-phenylpropanediol-1,2 has m.p. 44°.

The 7th fraction was 1,2-dichloro-2-phenylpropane (III) with traces of the monochlorides (I) and (II).

The 8th fraction was a mixture of dichloride (III) and the unsaturated nitro compound (IV); n^{20}D 1.5518 to 1.5683.

The 9th fraction, with n^{20}D 1.5758, was mainly the unsaturated nitro compound (see fraction 10).

The 10th fraction was a viscous yellow liquid with a sharp lachrimatory smell, which was insoluble in water, but dissolved readily in alkalies. It decolorized a solution of bromine in carbon tetrachloride and an acetone solution of potassium permanganate.

d^{20}_4 1.1527, n^{20}D 1.5803, MR$_D$ 47.08; calc. 45.51.

Found %: N 8.26, 8.29. $C_9H_9O_2N$.

Calculated %: N 8.59.

The substance did not change during long storage. Reduction with zinc amalgam in hydrochloric acid was accompanied by elimination of the nitro group and hydroxylamine and ammonia were detected in the reaction products. Elimination of the nitro group also occurred during hydrogenation over Raney nickel.

The fraction with b.p. 121-123° at 4 mm was 1-nitro-2-phenylpropene-1 (IV).

Hydrogenation of the 10th fraction into 1-nitro-2-phenylpropane. When 1.85 g of substance in 50 ml of an-hydrous alcohol was hydrogenated at room temperature over a palladium catalyst, 205 ml of hydrogen (0°, 760 mm) was absorbed over a period of 19 hours. One double bond required 248 ml of hydrogen. The alcohol solution yielded 0.7 g of 1-nitro-2-phenylpropane as a colorless liquid with a slightly pungent smell.

d^{20}_4 1.1099, n^{20}D 1.5392, MR$_D$ 46.63; calc. 45.99.

Found %: N 8.53, 8.28. $C_9H_{11}O_2N$.

Calculated %: N 8.48.

The hydrogenation product did not decolorize a solution of bromine in carbon tetrachloride, and gave a Konovalov reaction for a primary nitro group [14].

Conversion of 1-nitro-2-phenylpropene-1 (IV) into a carboxylic acid. 5.6 g of the substance, and 40 ml of hydrochloric acid (d 1.19) were heated in a sealed ampule on a boiling water bath for 6 hours. The aqueous layer and the dark oily layer were treated separately. A crystalline substance was extracted from the aqueous layer with ether. After recrystallization from ligroine (b.p. up to 60°), the substance (0.2 g) had m.p. 80-81°. A Beil-stein test for halogen was positive. The neutralization equivalent was determined by a micromethod.

Found: equiv. 170.9, 171.6. $C_6H_5CCl(CH_3)COOH$.

Calculated: equiv. 184.6. $C_6H_5C(OH)(CH_3)COOH$.

Calculated: equiv. 166.1.

According to [15], α-chloro-α-phenylpropionic acid has m.p. 75-76°, and according to [16], α-hydroxy-α--phenylpropionic acid has m.p. 94-95°.

The aqueous solution was evaporated to dryness and in the solid residue were identified hydroxylamine hy-drochloride and ammonium chloride (formation from hydroxylamine, see [17]).

The oily layer was treated twice with sodium carbonate solution with heating on a water bath and the soda extracts were boiled with bone charcoal, filtered, and acidified with dilute sulfuric acid. The acid solution was extracted with ether, the ether evaporated, and the dry residue recrystallized from ligroine. We obtained 0.1 g of white, star-like crystals with m.p. 108.5-109.5°. A Beilstein test for halogen was positive. The neutralization equivalent was found to be greater than that required for α-phenylacrylic acid. According to [18], α-phenylacrylic acid has m.p. 106-107°.

SUMMARY

1. The interaction of nitrosyl chloride with α-methylstyrene in ether solution yielded as the main products 1-chloro-2-phenylpropene-1, 1-chloro-2-phenylpropene-2, and 1,2-dichloro-2-phenylpropane. The reaction products were also found to contain 1-nitro-2-phenylpropene-1 and acetophenone. An explanation is given for the formation of these compounds.

2. The composition of the products isolated indicates that, under the conditions described for the reaction with α-methylstyrene, nitrosyl chloride acts mainly as a chlorinating, and partly as an oxidizing, agent.

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* Original Russian pagination. See C.B. translation.

INVESTIGATION IN THE FIELD OF ALKANESULFONIC ACIDS

## XIX. CHLORINATION OF N-ARYLAMIDES OF METHANESULFONIC ACID

A. G. Kostsova, R. Kh. Gershman and V. T. Akin'shina

Voronezh State University

Original article submitted March 28, 1958

The aim of the present work was to study the chlorination of the anilide, toluidides, and anisidides of methanesulfonic acids. As experiments showed, the anilide was chlorinated with the formation of the 2,4-dichloro-anilide, both in the case of the anilides of ethane- and butanesulfonic acids [1]; the reaction gave better yields in the presence of ZnO; the p-toluidide was chlorinated to the tetrachloro-p-toluidide, but in this case the presence of ZnO hindered the reaction. During chlorination of the o-toluidide, in the first 5 minutes rapid formation and separation of the crystalline monochloro-o-toluidide was observed; with an increase in the chlorination time (up to 45 minutes), a mixture of the mono- and tetrachloro-p-toluidides was formed. Chlorination of the o- and p-anisidides led to the dichloroanisidides; here, the side products formed were tetrachlorobenzoquinone, in the case of the p-anisidide, and the tetrachloro-o-anisidide, in the case of the o-anisidide. The results described were obtained by chlorination with gaseous chlorine. If the same chlorination were carried out with a solution of chlorine in dichloroethane, with ratios of chlorine to starting toluidide of 1:1, 1:2, 1:3, and 1:4, then the main products from the chlorination of the p- and o-toluidides were the monochlorotoluidides with the best yields at a reagent ratio of 1:2; in this case, the tetrachlorotoluidides were formed as side products in very small amounts. When the anisidides were chlorinated by the same method, the same dichloroanisidides were formed, but in the case of the p-anisidide, the yields were lower.

The position of the chlorine in the nucleus in the chlorination products obtained was demonstrated by hydrolysis to the corresponding amine, but this was not conclusive in all cases since the isomeric monochloro-o-toluidines and their N-acetyl derivatives have very similar constants, for example: 1) CH_3CONH—(ring with CH_3 and Cl)

m.p. 139-140°, and 2) CH_3CONH—(ring with CH_3)—Cl m.p. 140°.

Assuming that in the p-toluidide, the chlorine was oriented by the alkylsulfonamido group (consequently, in the o-toluidide, also), we consider that the monochloro-o-toluidine we obtained by hydrolysis most probably had the structure (2). Hydrolysis of the chloro-o-anisidide yielded a dichloro-o-anisidine, which is not described in the literature. Analysis data and the constants of the substances obtained are given in Table 1.

EXPERIMENTAL

Chlorination of methanesulfonanilide. The solvent used was dichloroethane, in which N-arylamides of methanesulfonic acid are more soluble than in CCl_4, which we used in the chlorination of the N-arylamides of other alkanesulfonic acids. To a solution of 2 g of anilide in 10 ml of dichloroethane was added 0.93 g of ZnO and a moderate stream of chlorine passed in (through a bottle with H_2SO_4) with cooling to from 0-5° for 45 minutes. At the end of the reaction, the mixture was left until the following day. Evaporation of the dichloroethane left

TABLE 1

№	Formula and name of chloro derivatives of N-arylamides of methane sulfonic acids (R = CH₃SO₂NH-)	Melting point	Empirical formula	% N		% Cl		% S	
				found	calc.	found	calc.	found	calc.
1	(structure) 2,4-Dichloroanilide	114—115°	$C_7H_7O_2Cl_2NS$	5.78	5.85	29.90	29.58	13.25	13.30
2	(structure) 3-Chloro-p-toluidide	103—105	$C_8H_{10}O_2ClNS$	6.04	6.37	15.84	16.17	15.06	14.57
3	(structure) 5-Chloro-o-toluidide	146—147	$C_8H_{10}O_2ClNS$	6.07	6.37	15.98	16.17	14.40	14.57
4	(structure) Tetrachloro-p-toluidide	154—156	$C_8H_7O_2Cl_4NS$	4.43	4.33	43.81	43.65	10.18	9.90
5	(structure) Tetrachloro-o-toluidide	178—180	$C_8H_7O_2Cl_4NS$	4.50	4.33	43.51	43.65	10.06	9.90
6	(structure) 2,5-Dichloro-p--anisidide	172—174	$C_8H_9O_3Cl_2NS$	5.02	5.18	25.78	26.35	11.16	11.87
7	(structure) Tetrachlorobenzo-quinone	290 (with decomp)	$C_6O_2Cl_4$	—	—	57.50	57.22	—	—
8	R—C₆H₃Cl₂OCH₃ Dichloro-o-anisidide	131—133	$C_8H_9O_3Cl_2NS$	5.34	5.18	26.38	26.35	12.50	11.87
9	(structure) Tetrachloro-o--anisidide	168—171	$C_8H_7O_3Cl_4NS$	4.26	4.13	41.82	41.88	9.51	9.43

TABLE 2

Time chlorine passed (in min)	Molar ratio of toluidide to chlorine	Reaction temperature	Reaction products isolated (in %)			
			monochloro--p-toluidide	tetrachloro--p-toluidide	monochloro--o-toluidide	tetrachloro--o-toluidide
5	1 : 5.5	18—0°	—	—	95.5	—
15	1 : 16.5	12—4	—	24.2	57.8	Traces
15	1 : 16.5	9—2	Traces	33.8	51.1	12.1
30	1 : 33	13—0	•	42.3	30.3	—
30	1 : 33	8—0	•	56.5	47.8	19.0
45	1 : 49.5	9—0	•	42.3	29.8	Traces
45	1 : 49.5	15—7	•	36.5	47.2	11.3

TABLE 3

Amt. of chlorine (in g)	Molar ratio of reagents	Reaction temp.	Reaction products isolated (in %)	
			monochloro--p-toluidide	monochloro--o-toluidide
0.76	1 : 1	20°	62	50
1.52	1 : 2	21—22	79	66.7
2.28	1 : 3	23—24	70	59.7
3.04	1 : 4	21—23	50	45.8

TABLE 4

Chlorination time (in min)	Molar ratio of anisidides to chlorine	Reaction temp.	Reaction products isolated (in %)			
			dichloro-p--anisidide	tetrachloro-benzoquin-one	dichloro-o--anisidide	tetrachloro--o-anisidide
15	1 : 18	39—14°	51.12	4.91	39.80	2.76
15	1 : 18	10—2	55.50	2.18	71.14	—
30	1 : 36	40—9	43.28	3.68	12.93	6.71
30	1 : 36	13—1	57.50	Traces	27.76	8.3
45	1 : 54	34—12	50.37	7.78	10.44	4.74
45	1 : 54	16—2	48.0	4.47	25.22	6.71

TABLE 5

Chlorination time (in min)	Molar ratio of anisidides to chlorine	Reaction temperature	Reaction products isolated (in %)			
			dichloro-p--anisidide	tetrachloro-benzo-quinone	dichloro-o-anisidide	tetrachloro-o-anisidide
0.70	1 : 1	27—28°	—	—	10.41	—
1.40	1 : 2	31—39	—	1.63	57.46	—
2.10	1 : 3	30—37	10.44	3.26	69.40	—
2.80	1 : 4	29—32	41.04	Traces	71.64	—

the crystalline dichloroanilide in a yield of 2.44 g (87.14%). A reaction without ZnO was carried out analogously with the same amount of anilide, and the yield was 1.5 g (53.57%). The product was recrystallized from aqueous alcohol.

Chlorination of methanesulfonotoluidides. a) Chlorination with gaseous chlorine was carried out with a constant chlorine flow (198 ml/min) and with the same amount of toluidide (1.5 g), but the chlorination time and the reaction temperature were varied. At the end of the reaction, the mixture was left for a day and then, in the case of the p-toluidide, evaporation of the solvent left a thick yellow oil, which yielded a finely crystalline

precipitate of the tetrachloro-p-toluidide after treatment with cold alcohol. Treatment of the alcohol filtrate with water gave a crystalline precipitate, which was separated into mono- and tetrachloro-p-toluidides by fractional crystallization from alcohol, but with very low yields of the two compounds. In the case of chlorination of the o-toluidide, in the first 5 minutes the monochloro-o-toluidide was formed exclusively in good yield, but with an increase in the chlorination time, its yield decreased though the tetrachloro-o-toluidide was formed in small amounts, together with it. The tetrachloro-o-toluidide was separated from the monochloro compound by treatment with cold alcohol, in which the former was insoluble. The results of some experiments on the chlorination of the p- and o-toluidides of methanesulfonic acid are presented in Table 2.

b) Chlorination with a solution of chlorine in dichloroethane was carried out in the following way: 50 ml of dichloroethane was first weighed and then saturated with chlorine to a definite increase in weight and the chlorine content per ml of solution calculated. The chlorination was carried out by mixing solutions of 2 g of toluidide in 15 ml of dichloroethane and a solution of chlorine with calculated molar ratios of the reagents of 1:1, 1:2, 1:3; and 1:4. The mixture boiled up and a voluminous amount of HCl was liberated. The results of chlorination by this method are presented in Table 3.

The monochlorotoluidides of methanesulfonic acid were colorless, crystalline substances with a specific smell, and dissolved readily in benzene, acetone, alcohol, and dilute alkali; they were precipitated from the latter on acidification, and did not dissolve in water. The tetrachlorotoluidides were colorless crystalline substances, which differed from the monochlorotoluidides in that they dissolved in alcohol only on boiling, and did not dissolve in dilute alkalies, but darkened.

Chlorination of methanesulfonanisidides. The reaction was carried out similarly to that described above. In all experiments, 1.5 g portions of the original anisidide was used, and the chlorine input rate was 198 ml/ min. In the chlorination of the p-anisidide, crystals of the dichloroanisidide precipitated during the reaction. The crystals were isolated, and the dichloroethane evaporated from the filtrate to give a thick oil, which was treated several times with boiling alcohol. On cooling, the alcohol solution deposited golden yellow crystals of tetrachlorobenzoquinone. In chlorination of the o-anisidide, the crystalline dichloro product precipitated only after the reaction mixture had stood for a day and had been rubbed with a glass rod. The filtrate (after removal of the solvent) was treated with hot alcohol to yield the tetrachloro-o-anisidide. With an increase in the chlorination time (up to 45 minutes), the amount of dichloro-o-anisidide fell noticeably, while with p-anisidide, the chlorination time had little effect on the yield of dichloro-p-anisidide. Chlorination at a lower temperature (from 10 to 2°) produced better yields of both p- and o-chloro derivatives. The results of chlorinating o- and p-anisidides are presented in Table 4.

The p- and o-anisidides were chlorinated with a solution of chlorine in dichloroethane, similarly to the toluidides, with ratios of chlorine to original anisidide of 1:1, 1:2, 1:3, and 1:4. In all experiments, 2 g portions of anisidide were taken. The experiments showed that the p-anisidide was not chlorinated with a reagent ratio of 1:1, at a ratio of 1:2, only tetrachlorobenzoquinone was isolated, and at ratios of 1:3 and 1:4, the dichloro-p-anisidide and tetrachlorobenzoquinone were formed, but in low yields. The chlorination of o-anisidide by the same method gave the dichloro-o-anisidide in good yield, with the exception of the experiment where the components were in a ratio of 1:1.

The results of the chlorination are presented in Table 5.

The dichloro-p- and o-anisidides of methanesulfonic acid were colorless crystalline substances, which dissolved readily in acetone and benzene, dissolved in alcohol only on heating, and were insoluble in water. The former was sparingly soluble in dilute alkali, and the latter did not dissolve at all. The tetrachloro-o-anisidide formed colorless crystals, which were readily soluble in many organic solvents, dissolved in alcohol only on boiling, and were insoluble in alkali. The tetrachlorobenzoquinone, isolated as a side product in the chlorination of p-anisidide, was identified through its characteristic derivative with aniline (dianiline dichlorobenzoquinone) [2], which was obtained, by mixing alcohol solutions of tetrachlorobenzoquinone and aniline, in the form of dark crystals with a metallic irridescence.

Hydrolysis of chloro derivatives. The hydrolysis was carried out by the procedure described previously [1]. The dichloroanilide yielded 2,4-dichloroaniline with m.p. 61-63°. The monochloro-p-toluidide yielded 3-chlorotoluidine as an oil, which was converted into the N-acetyl derivative by treatment with acetyl chloride; the melting point and analysis of this derivative corresponded with literature data (118°) [3]. Hydrolysis of the

monochloro-o-toluidide and subsequent acetylation led to the N-acetyl derivative of 5-chloro-o-toluidine with m.p. 139-140°. The dichloro-p-anisidide gave 2,5-dichloro-p-anisidine with m.p. 78-80° [4] and the dichloro--o-anisidide yielded a previously undescribed dichloro-o-anisidine with m.p. 91-92°.

SUMMARY

1. A study was made of the chlorination of the anilide, toluidides, and anisidides of methanesulfonic acid under various conditions.

2. The effect of the structure of the N-arylamides and the reaction conditions on the character of the compounds formed was demonstrated.

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SYNTHESIS OF TRIALLYL PHOSPHATE

E. V. Kuznetsov and R. K. Valedinov

S. M. Kirov Chemicotechnological Institute, Kazan

Original article submitted April 9, 1958

Recently there has been a strong increase in the interest in unsaturated compounds of phosphorus. These compounds have been proposed as plasticizers, insecticides, additives to lubricating oils, starting materials for preparative syntheses, and for the preparation of polymers and copolymers.

Work on these compounds has been reviewed by Gefter [1]. In many papers it has been reported that the isolation of pure products is difficult due to vigorous decomposition or their polymerization during distillation.

The synthesis of triallyl phosphate from allyl alcohol and phosphorus oxychloride is described in the literature [2]. The reaction was carried out in toluene solution in the presence of pyridine with cooling to −35°. It was reported that, with this method of synthesis, distillation of the reaction mixture was accompanied by decomposition and often led to an explosion. Obviously, it is difficult to obtain sufficient amounts of pure product by this method. Therefore, only the boiling point of 80° at 0.5 mm was reported.

We developed a new method of synthesizing triallyl phosphate, which consisted of the oxidation of triallyl phosphite by passing dry oxygen through it at 70-80°. The advantages of this method are the great simplicity of the synthesis, which does not involve the necessity of cooling the reaction mixture to very low temperatures, and the absence of the danger from explosion during distillation. The synthesis was accomplished in two stages.

1. Triallyl phosphite was prepared by the method used by A. E. Arbuzov and V. M. Zoroastrova [3,4]

$$3CH_2=CH-CH_2OH + PCl_3 + 3C_5H_5N \rightarrow (CH_2=CH-CH_2O)_3P + 3C_5H_5N \cdot HCl.$$

2. The triallyl phosphite was oxidized by the method we developed

$$(CH_2=CH-CH_2O)_3P + 0.5O_2 \rightarrow (CH_2=CH-CH_2O)_3PO.$$

The course of the oxidation was controlled by the change in the refractive index.

Certain amounts of diallylphosphorous acid, formed during the synthesis of triallyl phosphite, did not hinder the oxidation and were readily removed by distillation of the oxidized product.

It should be noted that the separation of a mixture of diallyl phosphite and triallyl phosphite presents certain difficulties due to the small difference in the boiling points of these products, which are 97.5°-98.5° at 8 mm [5], and 83.5-86.5° at 9 mm [3,4], respectively.

By this method, we obtained pure triallyl phosphate and determined its constants for the first time. It was a colorless, mobile liquid with a garlic-like smell and b.p. 93-94° at 1 mm.

EXPERIMENTAL

Synthesis of triallyl phosphite. Into a 2-liter, three-necked flask, fitted with a stirrer, thermometer, dropping funnel, and reflux condenser, were placed 261 g of anhydrous allyl alcohol, 356 g of dry pyridine, and 1000 ml of ether. With continuous stirring and cooling to 0-5°, 206 g of phosphorus trichloride, dissolved in 250 ml of

ether, was added. The precipitate of pyridine hydrochloride was removed by filtration. The ether evaporated and the residue fractionated in vacuum. As a result of one distillation, 190 g of substance was obtained.

B.p. 89-93° (11 mm), $n^{20}D$ 1.4560. According to data in [3,4], b.p. 85.5-86.5° (9 mm), $n^{18}D$ 1.4595, d^{20}_0 0.9974.

Oxidation of triallyl phosphite. 150 g of triallyl phosphite was placed in a long tube fitted with a bubbler. The apparatus was heated in a thermostat in carbon tetrachloride vapor. Oxygen from a tank was dried with sulfuric acid and calcium chloride, and passed through the phosphite for 6 hours. During this time, the refractive index of the reaction mixture fell from 1.4560 to 1.4500. Vacuum distillation yielded the following fractions: 1st, 75-90° at 1 mm, 17 g, $n^{20}D$ 1.4520; 2nd, 90-95° at 1 mm, 130 g, $n^{20}D$ 1.4500.

The distillation proceeded to completion without the least sign of decomposition.

The first fraction was apparently a mixture of unoxidized starting triallyl phosphite, diallyl phosphite, and triallyl phosphate. A second distillation of the 2nd fraction yielded 125 g (83%) of triallyl phosphate with b.p. 93-95° at 1 mm. The product was redistilled for determination of the constants. Pure triallyl phosphate had the following constants.

B.p. 93-94° at 1 mm, d^{20}_4 1.0815, $n^{20}D$ 1.4500, MR_D 54.20; calc. 54.16.

Found %: P 14.29, 14.36. $C_9H_{15}O_4P$.

Calculated %: P 14.21.

Analysis for the presence of double bonds by the bromide-bromate method showed that the product was 99.97% pure.

SUMMARY

A new method is presented for synthesizing triallyl phosphate by oxidation of triallyl phosphite with dry oxygen at 76°. This method eliminates the danger of explosions during distillation.

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SYNTHESIS OF THIAZOLE DERIVATIVES

XIII. BENZTHIAZOLYLTHIAZOLES

V. M. Zubarovskii

Institute of Organic Chemistry, Academy of Sciences, UkrSSR

Original article submitted April 21, 1958

Benzthiazolyl-2 methyl ketone, which we synthesized previously [1], may serve as the starting material for preparing 2-methylbenzthiazolylthiazoles, that have not been described in the literature, but are of interest for the synthesis of polymethine dyes. In this work, the above ketone was brominated to give benzthiazolyl-2 bromo-methyl ketone (I), which was used for the synthesis of the benzthiazolylthiazoles (II) and (VII). An attempt to brominate benzthiazolyl-2 methyl ketone under the conditions used for brominating thiazolyl-2 methyl ketone [2] and 6-nitrobenzthiazolyl-2 methyl ketone [3], namely with bromine in carbon tetrachloride, was unsuccessful. It was found that the bromination of benzthiazolyl-2 methyl ketone proceeded readily in glacial acetic acid at 85 to 90°. This reaction proceeded very slowly at lower temperatures. Under the given conditions with a molar ratio of ketone to bromine of 2:1, half of the ketone used was converted into the ω-bromo derivative (I), while the rest was isolated as the hydrobromide. By hydrolysis of this salt and subsequent recrystallization of the hydrolysis product, it was possible to recover about 30% of the ketone taken for bromination. The crude bromoketone (I) contained traces of the original ketone, and they were removed completely only after several recrystallizations. The pure bromoketone (I) was a colorless, crystalline substance with m.p. 91.5°, which did not have lachrimatory properties.

The bromoketone (I) was subjected to the conversions illustrated in the scheme.
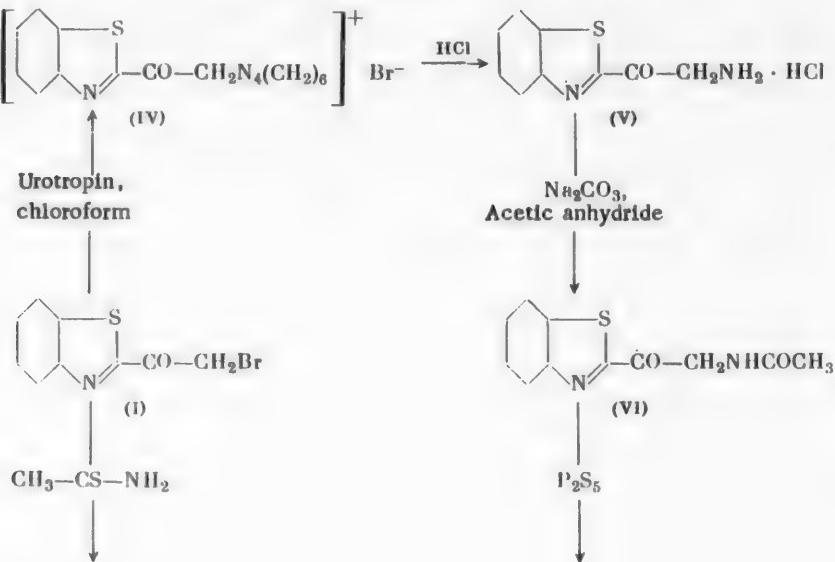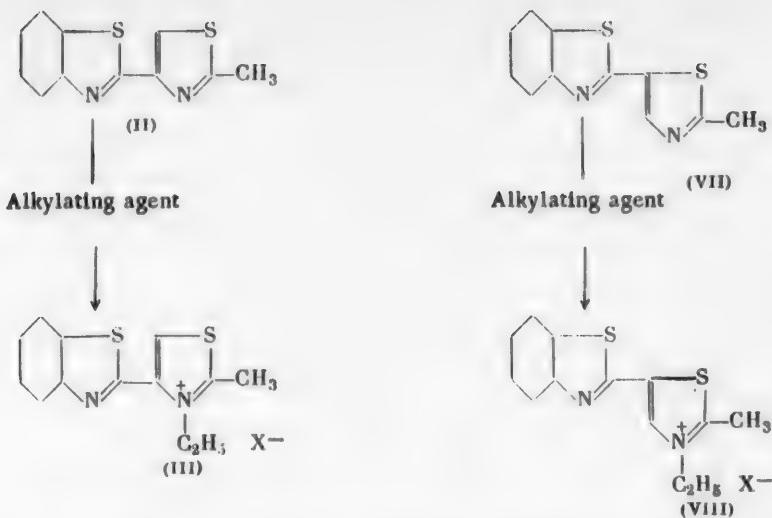
As a result of these conversions, we obtained the isomeric benzthiazolylthiazoles (II) and (VII), which were monoacidic bases, reminiscent in this respect of α-(benzthiazolyl-2')- and β-(benzthiazolyl-2')-pyridines [4]. The weak base (II) did not react at all when heated with excess ethyl iodide in a sealed tube at 150°. Under analogous conditions, the base (VII) gave an almost quantitative yield of the ethiodide (VIII; X = I). When a more active alkylating agent was used, namely ethyl p-toluenesulfonate, both bases were converted into quaternary salts (III; X = p-CH$_3$C$_6$H$_4$SO$_3$) and (VIII; X = p-CH$_3$C$_6$H$_4$SO$_3$), when of the two heterocyclic residues present in the molecules of the bases (II) and (VII), only one, the thiazole residue, took part in salt formation.

The structures of salts (III) and (VIII) were confirmed, first, by the presence of active methyl groups in them, in other words, by their capacity to form polymethine dyes, which were found to be insoluble in water; second, confirmation was provided by analysis data of the salts themselves and of the dyes synthesized from them. The polymethine dyes obtained from salts (III) and (VIII), belonged to different types: the dyes were "styryls" (IX) and (X), unsymmetrical thiazolothiacyanines (IX) and (XII), symmetrical thiazolocarbocyanines (XIII) and (XIV), and, finally, rhodacyanines (XV) and (XVI). In all the dye formulas presented below, R and R' are, alternatively, either a hydrogen atom or a benzthiazolyl-2 residue; the latter is designated by the letters BT. Each type of dye was represented by two isomeric compounds.

(XV) R = BT; R' = H; X = I
(XVI) R = H; R' = BT; X = I
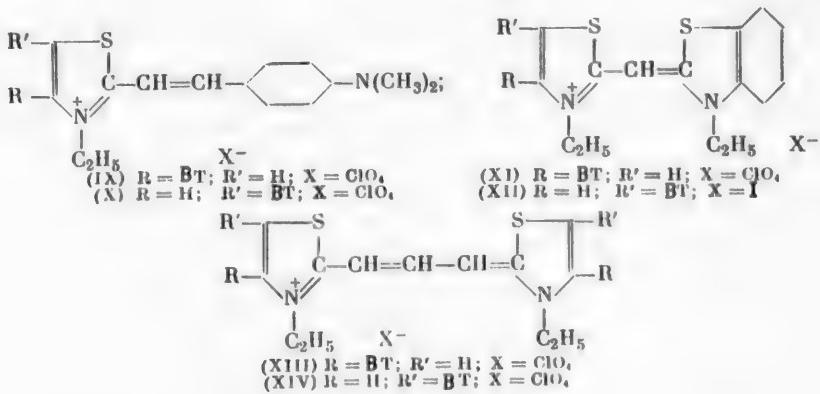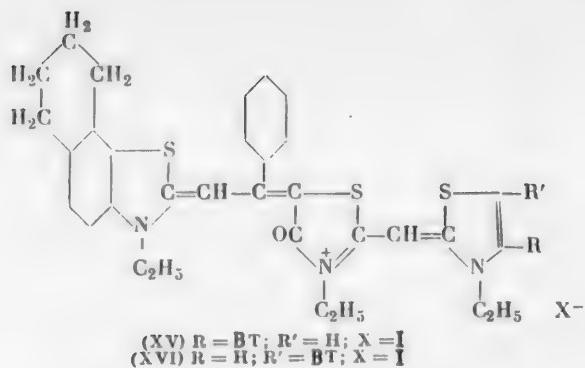
The light absorption maxima, determined in ethyl alcohol solution for all the dyes, are presented below.

Dye	Absorption maximum (in mμ)	Dye	Absorption maximum (in mμ)
(IX)	511	(X)	551
(XI)	420	(XII)	457
(XIII)	565	(XIV)	630
(XV)	607	(XVI)	635

From the data presented, it is obvious that the dyes which were derivatives of 2-methyl-5-(benzthiazolyl-2)-
-thiazole, had a considerably deeper color than the isomeric dyes of the same type which were derivatives of 2-
-methyl-4-(benzthiazolyl-2)-thiazole. For the symmetrical thiazolocarbocyanines (XIII) and (XIV), the differ-
ence in the values of the absorption maxima was 65 mμ. In general, the introduction of a benzthiazolyl-2 resi-
due into position 4 or 5 of the thiazole nucleus, forming part of the structure of polymethine dyes of various types,
produced bathochromic shifts in the absorption maxima of these dyes, which were insignificant in the first case,
and large in the second. These observations are analogous to those described by E. D. Sych, made in an investiga-
tion of thiazolocarbocyanines with aryl radicals in the thiazole nuclei [5].

EXPERIMENTAL

1. Benzthiazolyl-2 bromomethyl ketone (I). The benzthiazolyl-2 methyl ketone used for the synthesis was
recrystallized from aqueous acetone and had m.p. 108-110° [1]. Into a three-necked reactor, fitted with a mech-
anical stirrer, reflux condenser, thermometer, and dropping funnel, were placed 31.8 g of benzthiazolyl-2 methyl
ketone and 90 ml of glacial acetic acid. The reactor was heated on a paraffin bath, and when the temperature
inside the reactor reached 85-90°, the dropwise addition of 14.4 g of bromine in 240 ml of glacial acetic acid was
begun with rapid stirring. The bromine solution was added at a rate of 1 drop per second with the last third of the
solution added at half this rate. During the whole of the addition of the bromine solution, the temperature of the
mixture in the reactor was kept at 90-95°. Fifteen to 20 minutes after the beginning of bromination, a light cry-
stalline precipitate began to separate, and the amount of it gradually increased. The addition of all the bromine
solution required 4.5-5 hours. After the bromination, the contents of the reactor were cooled to 30° and the cry-
stalline precipitate collected by filtration at this temperature and washed with a small amount of glacial acetic
acid and dry ether. The crystalline precipitate and the acetic acid filtrate were treated separately. The ether-
washed crystalline precipitate was dried in air and then in a desiccator, when it weighed 18-18.7 g, had a yellow-
ish grey color, and had m.p. 192° (with decomp.). A mixture of this substance with the hydrobromide of benzthi-
azolyl-2-methyl ketone (m.p. 193° with decomp.) melted at 192° (decomp.).* All the ketone hydrobromide

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* The hydrobromide of benzthiazolyl-2 methyl ketone required for the identification was prepared by passing dry
hydrogen bromide into a hot solution of this ketone in glacial acetic acid with subsequent washing with dry ether.
When mixed with water, this salt was slowly hydrolyzed and converted into benzthiazolyl-2 methyl ketone.

obtained in this synthesis was mixed with 150 ml of warm water and left for 15 minutes with periodic stirring. The precipitate was collected by filtration, washed with water, and dried. The product weighed 13-14 g and was the original ketone with a small amount of bromoketone. For separation of the latter, the whole of the material was dissolved in 30 ml of chloroform and the solution decolorized by heating with charcoal (4 g) and filtered. The cooled filtrate was mixed with a solution of 3 g of urotropin in 40 ml of chloroform with a temperature of 30°, and left for 1 hour. The urotropin complex of the bromoketone was collected by filtration and washed with chloroform and dry ether. The dried complex weighed 1-1.7 g. The chloroform extract was again decolorized with charcoal, washed with warm water, dried with sodium sulfate, the whole of the chloroform removed, and the solid, brown residue (15 g) recrystallized from 90-100 ml of 60% aqueous acetone, with the mother solution decolorized 2-3 times with charcoal. By this method, we recovered 8-10 g of benzthiazolyl-2 methyl ketone with m.p. 105-108° (25-31% of that taken for the synthesis).

The acetic acid solution containing the bulk of the bromination product was decolorized by heating with charcoal (3 g), filtered, mixed with 700 ml of water, and cooled in ice and the white or pinkish white crystalline precipitate collected and washed with water. After being dried, the precipitate weighed 20-22 g. The whole of the crude bromoketone was recrystallized from 100 ml of alcohol with the alcohol solution twice decolorized with charcoal (1.0 and 0.5 g). The bromoketone, which precipitated as colorless, needle-like crystals on cooling, was filtered from the mother solution at 30° and washed once with a small amount of cooled alcohol. The yield was 9.5-11.5 g (41.3-49.8%); the m.p. was 85-86°. Further cooling of the mother solution yielded 3.5-4.5 g of crystals with m.p. 61-76°, which were the bromoketone with a trace of the original ketone; if the warm mother solution was diluted with water, then a product was isolated, which contained about 27% of bromine. It was best to isolate the bromoketone from this product in the form of the urotropin complex, of which 5.5-6.0 g was obtained. The complex was used for the synthesis of benzthiazolyl-2 aminomethyl ketone hydrochloride.

The bromoketone (I), obtained after the first recrystallization, still contained a small amount of the original ketone. For the repeated recrystallizations, 2 ml of alcohol was used per g of bromoketone, and the crystals were collected by filtration at 30°. The pure bromoketone (I) had m.p. 91.5°. The substance analyzed had been recrystallized three times.

Found %: Br 31.24, 31.33. C_9H_6ONSBr.

Calculated %: Br 31.25.

The bromoketone (I) formed colorless, prismatic needles with a very weak smell, reminiscent of that of benzthiazolyl-2 methyl ketone; it did not have lachrimatory properties.

2. 2-Methyl-4-(benzthiazolyl-2')-thiazole (II). Twice recrystallized bromoketone (I) with m.p. 89° was used for the synthesis. Two solutions were prepared, and one contained 2.56 g of the bromoketone in 5 ml of toluene; the other contained 0.75 g of thioacetamide in 15 ml of the same solvent. The hot solutions were mixed with the former added to the latter (the solution boiled) to give a turbid liquid, and then a viscous mass formed and rapidly changed into a yellow crystalline precipitate of the hydrobromide of the benzthiazolylthiazole (II) synthesized. After 10 minutes, the precipitate was collected and washed with dry ether. The salt (2.8 g) decomposed at 220° when melted. It was treated with a hot solution of 2.0 g of anhydrous sodium carbonate in 15 ml of water, and the base which precipitated was collected and washed with water. The product was recrystallized from 85 ml of alcohol (with charcoal), with the mother solution cooled for 1 hour in ice; the product was washed with cold alcohol. The yield of base was 1.3 g (56%). The pure benzthiazolylthiazole (II) formed colorless crystals with m.p. 176°, which had no smell; the substance dissolved in concentrated hydrochloric acid, but separated in the free state when water was added. The product analyzed was recrystallized twice from a 53-fold amount of alcohol (charcoal was used).

Found %: N 11.99, 11.97; S 27.40, 27.17. $C_{11}H_8N_2S_2$.

Calculated %: N 12.07; S 27.59.

When benzthiazolylthiazole (II) and ethyl iodide in a molar ratio of 1:10 were heated in a sealed glass tube for 3 hours at 150-160°, we obtained a brown, crystalline substance, which did not contain a quaternary salt according to color reactions, and had m.p. 175° (from ethanol), undepressed by admixture with the base (II) taken for the experiment.

When 2.3 g of benzthiazolylthiazole (II) was heated with 2.0 g of ethyl p-toluenesulfonate in a sealed glass tube for 4 hours at 150-160°, a quaternary salt was formed. The contents of the tube were dissolved in 35 ml of hot water and the unchanged base (0.2 g) removed by filtration. The filtrate was decolorized twice with charcoal, and the water evaporated, at first on a water bath and, finally, in a vacuum desiccator. The yield of the ethyl--p-toluenesulfonate of benzthiazolylthiazole, which was a clear, solid, very hygroscopic substance, was 4.0 g (92.5%). The salt could be used for the synthesis of polymethine dyes without further purification. The ethyl-p--toluenesulfonate was converted into the iodide by the usual method, and the latter was recrystallized three times from alcohol (with charcoal) to give yellowish white needle-like crystals with m.p. 202° (with subsequent decomposition).

Found %: I 32.69, 32.61. $C_{13}H_{13}N_2S_2I$.

Calculated %: I 32.73.

When the ethiodide obtained in this way was melted, it was converted completely into ethyl iodide and base (II), which had m.p. 176° after one recrystallization from alcohol.

3. Benzthiazolyl-2 aminomethyl ketone hydrochloride (V). Warm (30°) solutions of 5.12 g of bromoketone (I) with m.p. 86° in 10 ml of chloroform, and of 2.8 g of urotropin in 28 ml of chloroform were mixed. After several seconds, a light crystalline precipitate of the urotropin complex (IV) separated; the mixture heated up rapidly and its temperature reached 45-48°. After 1 hour, the precipitate was collected and washed many times with chloroform and dry ether. The yield of the complex was 7.4-7.8 g, i.e., almost theoretical. The well-washed substance was a white crystalline mass, which darkened at 140° and decomposed at 175° when heated in a capillary; when heated with most solvents, it changed to a considerable extent, and could not be recrystallized.

7.9 g of the well-washed urotropin complex (IV) was mixed with 30 ml of alcohol and the pasty mass formed was treated immediately with 8.5 ml of concentrated hydrochloric acid. The mass was immediately and rapidly heated with vigorous stirring until a yellow solution was formed, or until the solid product had almost completely dissolved. At this, an exothermal reaction began and proceeded with the evolution of benzthiazolyl-2 aminomethyl ketone hydrochloride (V) and ammonium salts. The mixture was left for 15-18 hours, cooled, and the solid product collected and washed with a very small amount of cooled alcohol and dry ether. The yield of the crude product was 4.2-5.0 g; it could be used for the preparation of benzthiazolyl-2 acetylaminomethyl ketone (VI) without further purification.

Pure benzthiazolyl-2 aminomethyl ketone hydrochloride was obtained by treating the crude product with the minimal amount of water cooled to 0° and then washing the material with cooled alcohol and ether. The salt purified in this way had m.p. 203° and was analyzed.

Found %: Cl 15.46, 15.38. $C_9H_9ON_2Cl$.

Calculated %: Cl 15.53.

The salt could be stored without change for a very long time.

4. Benzthiazolyl-2 acetylaminomethyl ketone (VI). 4.6 g of benzthiazolyl-2 aminomethyl ketone hydrochloride (V) was mixed with 10 ml of water, and to the suspension was added 10 g of ice and then, alternately over a period of 20-25 minutes, 4.1 g of acetic anhydride and 15 ml of a 20% aqueous solution of sodium carbonate were added in small portions with vigorous stirring. The acetylation had to be carried out in a large beaker due to the copious evolution of carbon dioxide. During the whole of the process, the mixture of reacting substances had to be kept pale yellow, and was not allowed to become pink for any length of time. If, after the acetylation, the mixture began to acquire a pink color on standing, a few drops of acetic anhydride had to be added. The acetyl derivative was filtered off from the cooled mixture, washed many times with water, and dried. The yield was 2.2 g (47%); for an unknown reason, the yield was considerably lower in some experiments. The acetyl derivative was purified by recrystallization from a 40-fold amount of benzene with the use of charcoal. After two recrystallizations, the substance was obtained as fine, colorless needles with m.p. 162-163°.

Found %: N 11.74, 11.65. $C_{11}H_{10}O_2N_2S$.

Calculated %: N 11.97.

5. 2-Methyl-5-(benzthiazolyl-2)-thiazole (VII). To a mixture of 1.17 g of (VI) and 1.1 g of finely powdered phosphorus pentasulfide was added 10 ml of dry toluene, and the mixture heated without stirring for 25 minutes in a small pear-shaped flask on a paraffin bath at 120°. At the beginning of heating when the solvent just began to boil, the flask was removed from the bath for a short time until the exothermal reaction ceased. After the heating, the toluene solution was poured out and to the solid residue was added 10 ml of a warm (45°) 10% aqueous solution of sodium hydroxide and 10 ml of toluene, and the mixture stirred carefully. The toluene was separated, and the alkaline liquid extracted twice more with warm toluene (5 ml portions). The combined toluene extracts were washed with 10 ml of 10% aqueous sodium hydroxide solution and then extracted 8 times with 15% hydrochloric acid (a total of 50 ml) and the acid solution partly decolorized with charcoal and treated with 20% aqueous sodium hydroxide solution (about 45 ml) with cooling, until an alkaline reaction appeared. The precipitated benzthiazolyl-thiazole (VII) was washed with water and recrystallized (with charcoal used) from 7 ml of alcohol. The yield was 0.5 g (43%). The base formed colorless hexagonal prismatic tablets with m.p. 121°, and m.p. 122° after a second recrystallization.

Found %: N 12.05, 12.15; S 27.67. $C_{11}H_8N_2S_2$.

Calculated %: N 12.07; S 27.59.

When benzthiazolylthiazole (VII) and ethyl iodide in a molar ratio of 1:10 were heated in a sealed glass tube at 150-160° for 3.5 hours, the iodoethylate was formed in 92% yield, and this was washed with acetone and dry ether and recrystallized from anhydrous alcohol to give clear, colorless needles with m.p. 265° (decomp.).

Found %: I 32.54, 32.65. $C_{13}H_{13}N_2S_2I$.

Calculated %: I 32.73.

When equimolecular amounts of (VII) and ethyl-p-toluenesulfonate were heated under the same conditions as for the formation of the ethiodide, the ethyl-p-toluenesulfonate of the base (VII) was formed in up to 90% yield, and when this had been washed with warm acetone and dry ether, it appeared as a greyish white crystalline substance, which was quite pure enough for use in the synthesis of polymethine dyes.

6. 2-(p-Dimethylaminostyryl)-4-(benzthiazolyl-2')-3-ethylthiazolium perchlorate (IX). A mixture of 0.43 g of the ethyl-p-toluenesulfonate (III), 0.15 g of p-dimethylaminobenzaldehyde, and 5 ml of dry pyridine was boiled for 1 hour. The dye was precipitated by the addition of excess ether, washed with ether and water by decantation, and converted into the perchlorate by the usual method. The yield of dye was 0.25 g (51%). After recrystallization from alcohol, the dye (IX) was obtained as reddish brown crystals with a metallic luster and with m.p. 234° (with decomp.)*; the absorption maximum was at 511 mμ (alcohol). For analysis, (IX) was recrystallized twice.

Found %: Cl 7.06, 7.11. $C_{22}H_{22}O_4N_3S_2Cl$.

Calculated %: Cl 7.22.

7. 2-(p-Dimethylaminostyryl)-5-(benzthiazolyl-2')-3-ethylthiazolium perchlorate (X). The dye was synthesized similarly to the previous one from 0.39 g of the ethiodide (VIII) and 0.15 g of p-dimethylaminobenzaldehyde. A crystalline precipitate of the dye separated even during the time that the starting materials were being heated in the solvents. The dye was washed with hot water, alcohol, and ether. The dye yield was 0.26 g (50%). After two recrystallizations from a large amount of alcohol, the iodide appeared as fine brownish violet needles with a metallic luster and m.p. 253° (with decomp.); the absorption maximum was at 551 mμ (alcohol). The iodide was converted into the perchlorate (X) by the usual method: the fine, pinkish grey, needle-like crystals had m.p. 264° (with decomp.). The perchlorate was analyzed.

Found %: Cl 7.28, 7.16. $C_{22}H_{22}O_4N_3S_2Cl$.

Calculated %: Cl 7.22.

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*In determining the melting points of the dyes, a capillary with the substance was introduced into a hot salt bath at a temperature 25-30° below the melting point of the dye investigated.

8. [4-(Benzthiazolyl- 2') -3-ethylthiazole-2] - [3"-ethylbenzthiazole- 2"] -monomethinecyanine perchlorate (XI). A mixture of 0.87 g of the ethyl-p-toluenesulfonate (III), 0.76 g of the ethyl-p-toluenesulfonate of 2-methylmercaptobenzthiazole, 10 ml of anhydrous alcohol, and 0.18 g of anhydrous sodium acetate was boiled for 40 minutes, after which 2.5 g of sodium perchlorate in 20 ml of water, and 5 ml of alcohol was poured into the hot solution. After 30 minutes, the yellow precipitate of the dye was collected and washed with hot water, alcohol, and ether. The yield of dye (XI) was 0.35 g (33.3%). It was recrystallized from 35 ml of glycol and then from 150 ml of alcohol; the m.p. was 256° (with decomp.); the absorption maximum lay at 420 mμ (alcohol).

Found %: Cl 6.95, 6.82. $C_{22}H_{20}O_4N_3S_3Cl$.

Calculated %: Cl 6.81.

9. [5-(Benzthiazolyl- 2') -3-ethylthiazole-2] - [3"-ethylbenzthiazole- 2"] -monomethinecyanine iodide (XII). The procedure for synthesizing this dye differed slightly from the previous one: when a mixture of 0.54 g of the ethyl-p-toluenesulfonate (VIII), 0.48 g of the ethyl-p-toluenesulfonate of 2-methylmercaptobenzthiazole, 8 ml of anhydrous alcohol, and 0.12 g of anhydrous sodium acetate had been boiled, the solution formed was left for 15 hours. The precipitated dye was collected and washed with hot water, alcohol, and ether. The yield was 0.4 g (58%). The crude dye was converted into the iodide by the usual method, and this was recrystallized twice from a large amount of alcohol. The pure dye (XII) had m.p. 277° (with decomp.) and an absorption maximum at 457 mμ (alcohol).

Found %: I 22.78, 22.72. $C_{22}H_{20}N_3S_3I$.

Calculated %: I 23.13.

10. 3,3'-Diethyl-4,4'-di-(benzthiazolyl-2")-thiazolocarbocyanine iodide (XIII). A mixture of 0.86 g of the ethyl-p-toluenesulfonate (III), 0.74 g of ethyl orthoformate, and 5 ml of dry pyridine was boiled for 1 hour and, after cooling, was then poured into 100 ml of dry ether. After 15 hours, the precipitated dye was washed several times with ether by decantation, treated with water, collected by filtration, washed with water several times, and dried. The yield was 0.15 g (21.4%). The ethyl-p-toluenesulfonate of the dye was converted into the iodide, and the perchlorate by the usual method. The iodide formed fine violet-brown crystals with a metallic luster and had m.p. 215° (with decomp.) and an absorption maximum at 565 mμ (alcohol). The perchlorate of (XIII) had m.p. 264° (with decomp.). The perchlorate was analyzed.

Found %: Cl 5.52, 5.77. $C_{27}H_{23}N_4S_4Cl$.

Calculated %: Cl 5.63.

11. 3,3'-Diethyl-5,5'-di-(benzthiazolyl-2")-thiazolocarbocyanine perchlorate (XIV). 0.86 g of the ethyl-
-p-toluenesulfonate (VIII), 0.74 g of ethyl orthoformate, and 10 ml of anhydrous pyridine were heated together on a paraffin bath with a temperature of 115°. Even at the beginning of heating, the mixture thickened due to the formation of a voluminous microcrystalline precipitate of the dye. When the mixture had cooled, the precipitate was collected and washed with a small amount of methyl alcohol, many times with water, again with alcohol, and finally with ether. The yield was 0.45 g (63.3%). After recrystallization from a large amount of alcohol, the dye was obtained as violet-grey crystals with a metallic luster,which had m.p. 297° (with decomp.) and an absorption maximum at 630 mμ (alcohol). By the usual method, the dye was converted into the perchlorate (XIV), which had m.p. 267° (with decomp.) after many washes with hot water, alcohol, and ether.

Found %: Cl 5.58, 5.45. $C_{27}H_{23}O_4N_2S_4Cl$.

Calculated %: Cl 5.89.

12. 3,3'-Diethyl-4'-(benzthiazolyl-2")-4-keto-5-[β-(3"-ethyl-6",7"-tetramethylenebenzthiazolinylidene-
-2")-α-phenylethylidene]-thiazolinothiazolomonomethinecyanine iodide (XV). For the preparation of this dye, we used 3-ethyl-5-[(3"-ethyl-6",7"-tetramethylenebenzthiazolinylidene-2")-α-phenylethylidene]-rhodanine, which will be called, in short, "merocyanine," below. 0.48 g of merocyanine and 0.63 g of dimethyl sulfate were heated at 125° (in the mixture) for 25 minutes. The mercocyanine salt formed was powdered, washed several times with dry ether, and dissolved in 1.5 ml of dry pyridine and the solution obtained was mixed with a warm solution of 0.86 g of the ethyl-p-toluenesulfonate (III) in 1.5 ml of the same solvent. The mixture was boiled for 1.5 hours, and then to it was added 5 ml of 80% alcohol. After 20 hours, the dye crystals were collected, washed with dilute

alcohol, ground to a powder, and washed many times on a filter with hot toluene until the filtrate became almost colorless. The dye yield was 0.32 g (40%). The dye was converted into the iodide (XV), which was recrystallized from alcohol to give fine, brownish green crystals with a bronze luster and m.p. 246° (with decomp.); the absorption maximum was at 607 mμ (alcohol).

Found %: I 15.52, 15.32. $C_{39}H_{37}ON_4S_4I$.

Calculated %: I 15.26.

13. 3,3'-Diethyl-5'-(benzthiazolyl-2")-4-keto-5-[β-(3"-ethyl-6",7"-tetramethylenebenzthiazolinylidene-
-2")-α-phenylethylidene]-thiazolinothiazolomonomethinecyanine iodide (XVI). In analogy with the previous experiment, a salt was prepared from 0.48 g of merocyanine. Heating this with 0.86 g of the ethyl-p-toluenesulfonate (VIII) and 5 ml of pyridine yielded a dye which, in contrast to the previous one, separated when the mixture of starting materials was boiled. The dye was washed with 80% aqueous alcohol, hot toluene, and ether. The yield was 0.55 g (68.6%). The crude dye was dissolved in 250 ml of chloroform and purified twice by chromatography on Al_2O_3. A 20% solution of methyl alcohol in chloroform was used for elution. Finally, the dye was converted into the iodide (XVI), which was recrystallized from glycol (methyl alcohol and dry ether were added to the mother solution). The dye (XVI) was a dark, finely crystalline powder with a metallic bronze luster and m.p. 292° (with decomp.); the absorption maximum was at 635 mμ (alcohol).

Found %: I 15.40, 15.39. $C_{39}H_{37}ON_4S_4I$.

Calculated %: I 15.26.

SUMMARY

1. The action of bromine on benzthiazolyl-2 methyl ketone in glacial acetic acid yielded benzthiazolyl-2 bromomethyl ketone, and some of its conversions were investigated.

2. Two new heterocyclic bases were synthesized, namely, 2-methyl-4-(benzthiazolyl-2')-thiazole and 2-methyl-5-(benzthiazolyl-2')-thiazole.

3. From the quaternary salts of these benzthiazolylthiazoles we synthesized polymethine dyes of various types and determined the position of their main light absorption maxima.

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INVESTIGATION IN THE FIELD OF ORGANIC SCINTILLATION MATERIALS

II. SYNTHESIS OF 2-ARYL DERIVATIVES OF 1,3,4-OXADIAZOLE

A. P. Grekov, O. P. Shvaika and L. M. Egupova

Kharkov Branch of the All-Union Chemical Reagents Scientific Research Institute

Original article submitted May 24, 1958

For a systematic investigation of oxadiazole derivatives aimed at determining the relation between chemical structure and scintillation efficiency, we synthesized and studied a series of new 2-aryl derivatives of 1,3,4-

-oxadiazole of the general formula R—[structure: N——N ring with O], where R = $4\text{-}H_3CO\text{-}C_6H_4$, $4\text{-}H_3CC_6H_4$, $4\text{-}H_2NC_6H_4$, $4\text{-}(H_3C)_2NC_6H_4$, $4\text{-}BrC_6H_4$, $4\text{-}H_5C_2OOCC_6H_4$, $4\text{-}H_5C_6C_6H_4$, and 2-furyl. It should be noted that, apart from the single paper by Ainsworth [1], who obtained several representatives of this series for the first time, monosubstituted 1,3,4-oxadiazoles have not been investigated further by anyone, as far as we know.
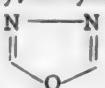
Most of the substances described in the present work were synthesized by interaction of the appropriate hydrazide with excess ethyl orthoformate by the equation:
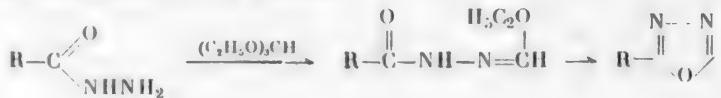
The reaction for the preparation of oxadiazole proceeded at the boiling point of ethyl orthoformate, and it was found that the heating time could be stopped at the moment of complete solution of the hydrazide in the orthoester, which usually required several hours. The oxadiazole formed was isolated from the reaction mixture, after removal of the excess orthoester, by vacuum distillation if the melting point was low enough, or by recrystallization from appropriate solvents.

The method of preparing 2-aryl derivatives of 1,3,4-oxadiazole from hydrazides and ethyl orthoformate is only applicable when the functional substituents in the original hydrazides are inert toward the orthoester. For example, we were unable to use this method for synthesizing such compounds as 2-(4-aminophenyl)- and 2-(4-hydroxyphenyl)-1,3,4-oxadiazoles since the reaction yielded high-melting products of interaction of the corresponding hydrazides with the orthoester not only through the hydrazide, but also through the amino and hydroxy groups. Therefore, for preparing such derivatives, we started from appropriate conversions of functional groups in an already formed oxadiazole. Thus, 2-(4-aminophenyl)-1,3,4-oxadiazole was obtained from nitrophenyloxadiazole by reduction with phenylhydrazine according to the following equation [2]:
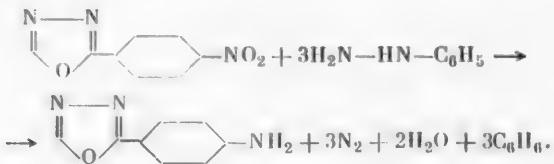
Reducing agents acting in acid or alkaline media, like zinc dust or sodium disulfide, for example, were un-successful since it was observed that, in contrast to 2,5-disubstituted derivatives, monosubstituted 1,3,4-oxadiazoles were readily hydrolyzed, even in the cold, with the formation of the corresponding hydrazides and formic acid:

$$\text{R}-\underset{\substack{\diagup\\\text{O}}}{\overset{\substack{\text{N}\!-\!-\!\text{N}\\\parallel\quad\parallel}}{}}\quad\xrightarrow[\text{H}^+]{\text{HOH}}\quad \text{HC}\underset{\text{OH}}{\overset{\text{O}}{\diagdown}}\ +\ \text{R}-\text{C}\underset{\text{NHNH}_2}{\overset{\text{O}}{\diagdown}}.$$

The 2-substituted 1,3,4-oxadiazoles synthesized in the present work were colorless, crystalline substances, which were difficultly soluble in water, but readily so in alcohol, benzene, and toluene. The amino group strongly reduced the solubility of oxadiazole in nonpolar organic solvents.

EXPERIMENTAL

1. Synthesis of 2-(4-methoxyphenyl)-1,3,4-oxadiazole. 66 g of methyl 4-methoxybenzoate [3] was mixed with 37 ml of 98% hydrazine hydrate in a flask fitted with a reflux condenser, and the mixture obtained was heated on a boiling water bath for 5 hours. Cooling the reaction mixture precipitated 2-methoxybenzhydrazide as a colorless, crystalline product, which was collected by filtration, washed on the filter with alcohol, and dried. The substance was recrystallized from water when the yield was 47 g (71%). The m.p. was 135° (136° [4]).

25 g of 4-methoxybenzhydrazide was mixed with 250 ml of ethyl orthoformate and boiled in a flask with a reflux condenser for 15 hours. Then, almost the whole of the ethyl orthoformate was removed and the residue vacuum distilled at 140-144° (4 mm). The yield was 22 g (83%). For further purification, the oxadiazole obtained, which had m.p. 61°, was vacuum distilled twice more and recrystallized from ligroine, when it had m.p. 63°.

2-(4-Methoxyphenyl)-1,3,4-oxadiazole was a colorless, crystalline substance, which was readily soluble in alcohol, benzene, and toluene, and less so in ligroine and water.

Found %: N 15.90. $C_9H_8O_2N_2$.

Calculated %: N 15.91.

2. Synthesis of 2-(4-bromophenyl)-1,3,4-oxadiazole. A mixture of 85 g of ethyl 4-bromobenzoate [4], 31 ml of 98% hydrazine hydrate, and 100 ml of ethanol was boiled in a flask with a reflux condenser for 10 hours. The 4-bromobenzhydrazide, which precipitated when the reaction mass was cooled, was collected by filtration, washed on the filter with water and a small amount of alcohol, and dried. After recrystallization from aqueous alcohol with activated charcoal, the product was obtained in a yield of 60 g (75%). The m.p. was 165° (164° [5]).

30 g of 4-bromobenzhydrazide was boiled under reflux with 150 ml of ethyl orthoformate for 15 hours. During this time, the whole of the hydrazide passed into solution. The bulk of the ethyl orthoformate was then removed by distillation, and the crystalline product left in the residue was collected, washed on the filter with a small amount of alcohol, and dried. When the product has been recrystallized from ethanol, the yield was 27 g (86%) and the m.p. 144°. After several further recrystallizations from ethanol, the product had m.p. 145°.

2-(4-Bromophenyl)-1,3,4-oxadiazole was a colorless, crystalline substance, which was readily soluble in alcohol, less so in benzene, toluene, and ligroine, and insoluble in water.

Found %: N 12.44. $C_8H_5ON_2Br$.

Calculated %: N 12.48.

3. Synthesis of 2-(4-methylphenyl)-1,3,4-oxadiazole. 29 g of ethyl 4-methylbenzoate [4] and 13 ml of 98% hydrazine hydrate were heated under reflux on a water bath for 10 hours. The reaction mixture was then cooled and the precipitated 4-methylbenzhydrazide collected, washed with ether on the filter, and dried. The yield was 22 g (76%) and the m.p. 104-105°. After two recrystallizations from aqueous ethanol, the product had m.p. 116° (117° [6]).

17 g of 4-methylbenzhydrazide was boiled in a flask under reflux with 200 ml of ethyl orthoformate until the hydrazide dissolved completely, which required about 8 hours. The excess orthoester was then removed, and the residue vacuum distilled at 122° (3 mm). The yield was 15 g (83%) and the m.p. 85-86°. After recrystalliza-tion from ethanol, the product had m.p. 86°.

2-(4-Methylphenyl)-1,3,4-oxadiazole was a colorless, crystalline substance, which dissolved readily in organic solvents and with difficulty in water.

Found %: N 17.72. $C_9H_8ON_2$.

Calculated %: N 17.50.

4. Synthesis of 2-(4-dimethylaminophenyl)-1,3,4-oxadiazole. Methyl 4-dimethylaminobenzoate was obtained by boiling a solution of 14 g of 4-dimethylaminobenzoic acid [7] with 65 ml of anhydrous alcohol in the presence of 2 ml of concentrated H_2SO_4 for 12 hours. The yield was 13.5 g (89%). The m.p. was 100°.

50 g of methyl 4-dimethylaminobenzoate was mixed with 24 ml of 98% hydrazine hydrate, and the mixture obtained was heated on a boiling water bath for 5 hours. The product, which precipitated after the reaction mass had cooled, was collected, washed with water on the filter, and dried. The yield was 26 g (52%). The m.p. was 168°. After recrystallization from water, the product had m.p. 171° (170-171° [8]).

A mixture consisting of 5.5 g of 4-dimethylaminobenzhydrazide and 50 ml of ethyl orthoformate was boiled in a flask with a reflux condenser for 7 hours. The bulk of the orthoformic ester was then removed, and the product remaining in the residue was collected by filtration and dried. The yield was 4 g (69%). The m.p. was 127°. After a benzene solution of the oxadiazole had been purified twice on a chromatography column filled with aluminum oxide, the product had m.p. 132°.

2-(4-Dimethylaminophenyl)-1,3,4-oxadiazole was a colorless, crystalline substance, which was readily soluble in organic solvents, but insoluble in water.

Found %: N 18.97. $C_{10}H_{11}ON_3$.

Calculated %: N 18.83.

5. Synthesis of 2-(4-aminophenyl)-1,3,4-oxadiazole. 45 g of ethyl 4-nitrobenzoate was dissolved in 50 ml of ethanol, and while the solution was heated on a boiling water bath, 15 ml of 98% hydrazine hydrate was added dropwise. The formation of a voluminous precipitate began immediately. After the addition of the hydrazine hydrate, the mixture obtained was heated for 20-30 minutes and then the reaction mixture was cooled and the precipitate of 4-nitrobenzhydrazide was collected by filtration and recrystallized from water. The yield was 36 g (86%). The m.p. was 210° (210° [9]).

88 g of 4-nitrobenzhydrazide and 550 ml of ethyl orthoformate were boiled in a flask with a reflux condenser until the hydrazide dissolved completely, which required about 10 hours. Then the excess orthoester was removed and the 2-(4-nitrophenyl)-1,3,4-oxadiazole, which precipitated from the residue on cooling, was filtered off and recrystallized from ethanol. The yield was 75 g (81%). The m.p. was 156° (156° [1]).

To 2 g of 2-(4-nitrophenyl)-1,3,4-oxadiazole was added 7 ml of freshly distilled phenylhydrazine, and the mixture slowly heated with stirring on a paraffin bath. At 90° a copious evolution of nitrogen began, and with stronger heating was accompanied by frothing of the reaction mass. When the rate of gas bubble evolution fell, heating was gradually increased and the temperature raised to 140-150° at the end of the reaction. The reaction was considered complete when the evolution of nitrogen practically ceased. The reaction mixture obtained was then cooled (a yellow, crystalline product separated), 5 ml of benzene added, and the substance collected by filtration, washed with benzene on the filter, and dried. A light yellow crystalline product was obtained. The yield was 1.5 g (89%), and the m.p. 136°. After chromatographic purification on charcoal, the substance was colorless and had m.p. 138°.

2-(4-Aminophenyl)-1,3,4-oxadiazole was a colorless, crystalline product, which was difficultly soluble in benzene, toluene, and water, but more soluble in alcohols.

Found %: N 26.12. $C_8H_7ON_3$.

Calculated %: N 26.08.

6. Synthesis of 2-(4-biphenylyl)-1,3,4-oxadiazole. 20 g of the hydrazide of 4-biphenylylcarboxylic acid [10] was boiled with 400 ml of ethyl orthoformate under reflux for 20 hours. If a small amount of an insoluble product remained after this, it was removed by filtration and then the bulk of the orthoester distilled off. The substance which precipitated on cooling was filtered off, washed with orthoester on the filter, and dried. A

colorless, crystalline product with m.p. 120° was obtained. A benzene solution of it was then purified chromatographically on aluminum oxide. The yield was 11 g (53%). The m.p. was 122°.

2-(4-Biphenylyl)-1,3,4-oxadiazole formed colorless crystals, which were readily soluble in benzene, alcohol, and ether, less soluble in ligroine, and insoluble in water.

Found %: N 12.41. $C_{14}H_{10}ON_2$.

Calculated %: N 12.61.

7. Synthesis of 2-(4-carbethoxyphenyl)-1,3,4-oxadiazole. A solution of 30 g of diethyl terephthalate and 9 ml of 98% hydrazine hydrate in 30 ml of anhydrous alcohol was heated on a boiling water bath for 5 hours. Cooling the reaction mixture precipitated crystalline 4-carbethoxybenzhydrazide, which was collected, washed with alcohol in the filter, and dried. The yield was 18.5 g (66%) and the m.p. 160-162°. After recrystallization from alcohol, the product had m.p. 164-165° (164-165° [11]).

1 g of 4-carbethoxybenzhydrazide and 20 ml of ethyl orthoformate were boiled under reflux for 15 hours. The excess orthoformic ester was removed by distillation, and the product was filtered from the residue and dried. The yield was 0.6 g (57%) and the m.p. 60°. After several recrystallizations from ligroine, the product had m.p. 83-83.5°.

2-(4-Carbethoxyphenyl)-1,3,4-oxadiazole was a colorless, crystalline substance, which was readily soluble in organic solvents and less so in water.

Found %: N 13.08. $C_{11}H_{10}O_3N_2$.

Calculated %: N 12.84.

8. Synthesis of 2-(2-furyl)-1,3,4-oxadiazole. 4 g of the hydrazide of furan-2-carboxylic acid [12] was mixed with 50 ml of ethyl orthoformate and carefully heated on a water bath. A vigorous reaction began immediately, and the whole of the precipitate dissolved rapidly. Heating was continued for a further 20 minutes after this. The excess ethyl orthoformate was then removed under reduced pressure, and the residue distilled at 140° (1 mm). The yield was about 3 g (70%). After chromatographic purification of a benzene solution on aluminum oxide, the substance had m.p. 53°.

2-(2-Furyl)-1,3,4-oxadiazole was a colorless, crystalline substance, which was readily soluble in organic solvents and insoluble in water.

Found %: N 20.89. $C_6H_4O_2N_2$.

Calculated %: N 20.60.

SUMMARY

1. Eight 2-substituted 1,3,4-oxadiazoles, which are not described in the literature, were synthesized, and their properties studied and the conditions for the preparation of the intermediate products were defined more accurately.

2. A route for the synthesis of amino derivatives of 1,3,4-oxadiazole was developed.

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SYNTHESIS OF SOME 1,4-PIPERAZINE-BIS-CARBOTHIOSULFENAMIDES

I. I. Éitingon, N. P. Strel'nikova and M. S. Fel'dshtein

Tire Industry Scientific Research Institute

Original article submitted May 9, 1958

There is contradictory data in the literature on the character of the products from the interaction of equimolar amounts of piperazine and carbon disulfide. The finely crystalline, light yellow substance obtained in this case corresponded in composition to the empirical formula $C_6H_{10}N_2S_2$. Under the name of Thioide [1], this substance found application as an anthelmintic, and also for the analytical determination of cobalt in the presence of nickel and copper. By heating Thioide with 0.1 N KOH solution, T. Pavolini and F. Gambarin [2] obtained a neutral potassium salt with the composition $C_{10}H_{12}N_4S_4K_2$ which, in their opinion, indicated the presence in the complex of compounds containing two sulfhydryl groups. By solution of Thioide in alkali and subsequent treatment with benzyl chloride, J. Dunderdale and T. Watkins [3] obtained a mixture of the benzyl esters of piperazinedithiocarboxylic-1 acid and piperazinedidithiocarboxylic-1,4 acid. In the opinion of these authors, the starting material was a complex consisting of the structural units of the mono- and didithiocarboxylic acids of piperazine.

As a result of the interaction of carbon disulfide with piperazine in an alkaline medium, and subsequent oxidative condensation of the reaction product with appropriate secondary aliphatic amines, we obtained two previously unknown substances, namely, 1,4-piperazine-bis-carbothiosulfendimethylamide (I) and 1,4-piperazine--bis-carbothiosulfendiethylamide (II).

$$R_2NS(S=)C-N\underset{CH_2\ CH_2}{\overset{CH_2\ CH_2}{\diamond}}N-C(=S)SNR_2$$

$$R = CH_3\ (I),\ C_2H_5\ (II)$$
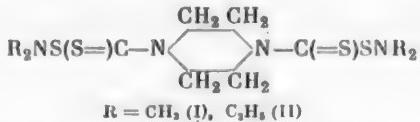
The formation of these substances gives grounds for proposing that the interaction of piperazine with carbon disulfide in an alkaline medium proceeds with the formation of the disodium salt of piperazine-bis-dithiocarboxylic--1,4 acid (III), which is the intermediate product in the formation of the sulphenamide derivatives by subsequent oxidative condensation with amines by the reaction:

$$NaS(S=)CN\underset{CH_2\ CH_2}{\overset{CH_2\ CH_2}{\diamond}}NC(=S)SNa + 2HN(R)_2 + 2J_2 \longrightarrow$$

$$(III)$$

$$\longrightarrow (R)_2NS(S=)CN\underset{CH_2\ CH_2}{\overset{CH_2\ CH_2}{\diamond}}NC(=S)SN(R)_2 + 2NaI + 2HI,\ \text{where}\ R = CH_3\ \text{or}\ C_2H_5.$$
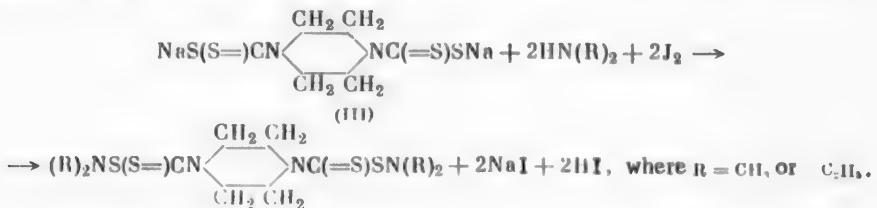
Both of the compounds obtained were found to be quite efficient accelerators of sulfur vulcanization for natural and synthetic butadiene-styrene rubber.

EXPERIMENTAL

Preparation of 1,4-piperazine-bis-carbothiosulfendimethylamide (I). Into a round-bottomed flask, fitted with a mercury seal, a reflux condenser, a dropping funnel, and a thermometer were placed 17.2 g of piperazine (in the form of the free base), 16 g of sodium hydroxide, and 320 ml of water. After the reaction mass had been cooled to 8-10°, 30.4 g of carbon disulfide was gradually added with stirring, over a period of 1 hour. The reaction mixture was then kept for 30 minutes at 18-20°. At this temperature, 720 g of a 25% aqueous solution of dimethylamine (180 g) was gradually added over a period of 1 hour. After the addition of the dimethylamine, the oxidative condensation was carried out. For this purpose, 101.6 g of iodine in 400 ml of 20% aqueous potassium iodide solution was gradually added at the same temperature over a period of 2 hours. The crystalline precipitate formed was collected, washed with water and then alcohol, and dried in air. The yield of 1,4-piperazine--bis-carbothiosulfendimethylamide was 38 g (58.6%). After washing with alcohol, the white, crystalline substance had m.p. 146-147°. The substance obtained was readily soluble in the cold in benzene and carbon tetrachloride and in alcohol and acetone on heating.

Found %: C 36.96; H 6.40; S 39.18; N 17.49. $C_{10}H_{20}S_4N_4$.

Calculated %: C 37.03; H 6.17; S 39.50; N 17.28.

Preparation of 1,4-piperazine-bis-carbothiosulfendiethylamide (II). The sulfenamide derivative with diethylamine was obtained similarly with the only difference that a larger excess of amine was used. We used 17.2 g of piperazine, 30.4 g of carbon disulfide, and 584 g of diethylamine. The amounts of sodium hydroxide and oxidant corresponded to those used for the preparation of (I). The white, crystalline substance obtained had m.p. 105-106° after washing with water and then alcohol. The yield of 1,4-piperazine-bis-carbothiosulfendiethyl-amide was 39.2 g (50.1%).

The substance dissolved readily in the cold in benzene, carbon tetrachloride, acetone, and ether, and in alcohol on heating.

Found %: C 44.30; H 7.54; S 33.81; N 14.85. $C_{14}H_{28}S_4N_4$.

Calculated %: C 44.21; H 7.37; S 33.68; N 14.73.

SUMMARY

1. The reaction of piperazine with carbon disulfide in an alkaline medium and subsequent oxidative condensation of the intermediate product with secondary aliphatic amines gave the corresponding sulfenamide derivatives. 1,4-Piperazine-bis-carbothiosulfendimethylamide and 1,4-piperazine-bis-carbothiosulfendiethylamide were synthesized and described for the first time.

2. The formation of these compounds by the synthesis described gives a basis for proposing that the condensation of piperazine with carbon disulfide in an alkaline medium forms the disodium salt of piperazine-bis-dithio-carboxylic-1,4 acid.

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SYNTHESIS AND SOME CONVERSIONS OF SULFIDES
OF THE THIOPHENE SERIES

Ya. L. Gol'dfarb, M. A. Kalik and M. L. Kirmalova

Institute of Organic Chemistry, Academy of Sciences, USSR

Original article submitted June 2, 1958

As was shown in a series of communications from our laboratory, published from 1952 on [1], and by certain foreign investigators, the reductive desulfurization of thiophene derivatives may be used for the preparation of many classes of aliphatic compounds. This method has found ever increasing application, for example, in the work of Buu-Hoi [2] and Badger et al. [3], who, unfortunately, did not mention our investigations.

One of the practical limitations of this method is connected with the fact that the α-position of the thiophene nucleus is most reactive and is usually entered by the functional group in substitution, and this ultimately determines the structure of the desulfurization product; derivatives of thiophene with functions in the β-position, which should act as starting compounds in appropriate cases, are still difficultly accessible, though certain new routes for their preparation have been found in recent years [4,5]. In certain cases, it is possible to attain the desired ends by using 2,5-dialkyl derivatives instead of thiophene itself, though the lengthening of the chain in the desulfurization product that this involves is often undesirable. In addition, if the substituent groups in such a thiophene homolog are different, then in the synthesis of its derivative further difficulties arise due to the possible formation of a mixture of isomers. Gronowitz [5] proposed the use of 2,5-dichlorothiophene as the starting material for the synthesis of 3-substituted thiophenes; the halogen could be removed readily at the appropriate stage. For some purposes, this route is undoubtedly useful, but in other cases the halogen atoms may have a negative deactivating effect on the thiophene ring. Another possible route to the preparation of aliphatic compounds, involving thiophene derivatives substituted in position 3, may be based on blocking of the α-position with a group activating the nucleus and readily removable during the desulfurization process. The alkylmercapto group has such properties. As far as we know, up to now only two alkyl thienyl sulfides have been described, namely, methyl 2--thienyl sulfide [7-9], and ethyl 2-thienyl sulfide [8]. A convenient method of synthesis from 2-thienylmagnesium iodide, sulfur and methyl iodide [9] gives a yield of 50-60%. As we found, methyl 2-thienyl sulfide and ethyl 5--ethyl-2-thienyl sulfide are obtained from the corresponding bromides* in approximately the same yield. A more convenient method of synthesizing sulfides of this type, making it possible to reach yields of about 80% is described in the experimental section. It involves the use of lithium derivatives of thiophene** and its homologs, which react with sulfur similarly to organomagnesium compounds. The important thing is that there is no need for preparing 2-halothiophenes. By this method, we prepared methyl 2-thienyl sulfide, ethyl 2-thienyl sulfide, methyl 5-methyl-2-thienyl sulfide, and ethyl 5-ethyl-2-thienyl sulfide; the identity of the latter with the sulfide obtained from 5-ethyl-2-thienylmagnesium bromide was established by comparison of their acetyl derivatives. We should note that the synthesis of methyl 2-thienyl sulfide by the method described required a certain (about 20%) excess of thiophene, as, otherwise, methyl butyl sulfide was formed, and this could not be separated by distillation, apparently due to its capacity for giving azeotropic mixtures with the alkyl thienyl sulfide. We did not observe such a phenomenon in other experiments and, for example, in the case of ethyl 2-thienyl sulfide, complete separation from the dialkyl sulfide was attained by one or two vacuum distillations.

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* We obtained the 5-bromo-2-ethylthiophene required for the synthesis in 75% yield by the action of a bromide-bromate mixture on 2-ethylthiophene.

** The metallation was carried out by the action of n-butyllithium.

By interaction with two moles of n-butyllithium and then with sulfur and methyl iodide, thiophene gave 2,5-bis-(methylmercapto)-thiophene (II) together with methyl 2-thienyl sulfide (I).

(I)   (II)

The action of acetyl chloride in the presence of stannic chloride on alkyl 2-thienyl sulfides, substituted with methyl or ethyl groups in position 5, gave high yields of the corresponding acetyl derivatives. On the other hand, under the same conditions, methyl 2-thienyl sulfide and 2,5-bis-(methylmercapto)-thiophene gave acetyl derivatives in considerably lower yields and tar formation was observed. This was apparently connected with the instability of the original sulfides toward acidic reagents. Methyl-2-thienyl sulfide was acetylated with acetic anhydride in the presence of orthophosphoric acid in somewhat better yield and, in this case, besides the monoacetyl derivative (III), a small amount of a substance was formed which corresponded in composition to the diacetyl derivative. Since the first of these compounds (see below) was 5-methylmercapto-2-acetothienone (III), the structure of the second may be represented by Formula (IV). Its formation is apparently caused by the activating action of the alkylmercapto group and, on the other hand, the coincidence of its orienting effect with that of the first acetyl group. The activating action of the alkylmercapto group may be explained by the fact that, in the acetylation of an equimolecular mixture of thiophene and methyl 2-thienyl sulfide with an insufficient amount of acetyl chloride in the presence of stannic chloride ("competing reactions" method), 2-acetothienone and (III) were isolated in yields of 15 and 48%, respectively; 77% of the thiophene was recovered unchanged.

(III)   (IV)

The structure of the monoacetyl derivative (III) was established on the basis of the fact that when treated with Raney nickel, hexanone-2 was formed. In addition, the reaction products contained a small amount of dodecanedione-2,11. As Badger et al. [10] showed, the latter is also formed in the reductive desulfurization of 2-acetothienone.
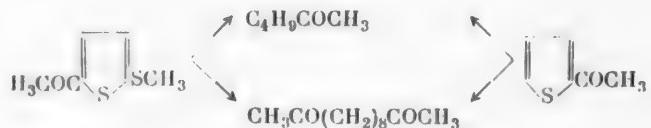
Starting from purely formal considerations, the acetylation product of alkyl 2-thienyl sulfides, substituted with alkyl radicals in position 5 of the thiophene ring, may be ascribed structure (V) or (VI). The choice between these two formulas was made on the basis of data from oxidation by King's method [11] and subsequent reductive desulfurization of 2-ethylmercapto-5-ethylthiophenecarboxylic acid with Raney nickel. This yielded methyl-n-butylacetic acid (VIII), which was identified in the form of the amide. The formation of this acid indicates that the starting acetyl derivative had structure (V) and not (VI), since only acid (IX) could have been obtained from the latter.

(V)   (VII)   (VIII)

(VI)   (IX)
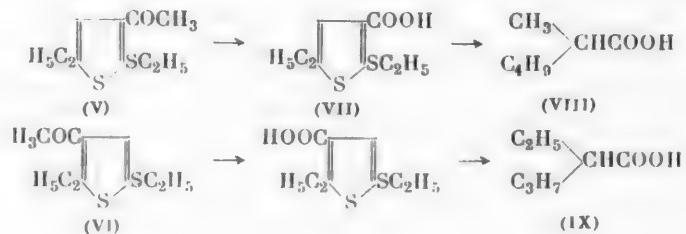
Alkyl thienyl sulfides of type (X) were readily brominated in the ortho position to the alkylmercapto group. Thus, the action of bromide—bromate solution on ethyl 5-ethyl-2-thienyl sulfide gave an 84% yield of a mono bromo derivative, whose structure was shown to be that of 3-bromo-5-ethylmercapto-2-ethylthiophene (XI) by its conversion into 2-ethylmercapto-5-ethyl-3-thiophenecarboxylic acid (VII).
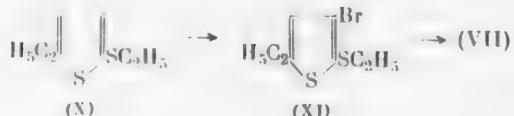
The data presented indicate that protecting the α-position in the ring of 2-alkylthiophenes by means of an alkylmercapto group makes it possible to obtain thiophene derivatives with functional groups in the β-position and ortho to this group. When treated with Raney nickel, such substances readily form compounds of the aliphatic series, corresponding in structure to the products of elimination of the ring and sulfide sulfur atoms. The introduction of an alkylmercapto group as a method of blocking the α-position of the thiophene ring is preferable to halogenation, which is used for the same purpose in some cases, since the thiophene ring is activated with respect to the action of electrophilic agents, and compounds containing such groups may be acylated by the Friedel-Crafts method, halogenated and metallated with organometallic compounds. In connection with this, it is necessary to remember that, in the acylation of α-bromo-substituted thiophenes by means of aluminum chloride, the halogen is frequently replaced by an acyl group [12]. We observed a similar phenomenon in the acetylation of 5-bromo--2-ethylthiophene in the presence of stannic chloride: the reaction product consisted of 5-ethyl-2-acetothienone and contained a much smaller amount of 5-bromo-2-ethylacetothienone of unestablished structure. In conclusion, we would like to report that we studied a method of eliminating the alkylmercapto group from alkyl thienyl sulfides, which made it possible to retain the thiophene ring; it included oxidation of the sulfide to the sulfoxide and subsequent action of butyllithium. This method will be described in detail in the next communication.

EXPERIMENTAL

5-Bromo-2-ethylthiophene. Over a period of 1 hour with stirring, 820 ml of an aqueous bromide—bromate solution with a bromine concentration of 64 g/liter was added to a mixture of 33.6 g of 2-ethylthiophene, 200 ml of ether, and 120 ml of conc. HCl, cooled to +(1-3)°, and the mixture was then stirred for 15 minutes without cooling. The ether layer was separated, the aqueous one extracted with ether, and the combined ether solution washed with water, 10% NaOH solution, and dried with calcium chloride. After removal of the ether, the residue was vacuum distilled. We obtained 43.6 g (75.3%) of 5-bromo-2-ethylthiophene with b.p. 76-78° (10 mm); $n^{20}D$ 1.5580 [78.5° (11 mm) [13], $n^{20}D$ 1.5570 [14]].

Preparation of alkyl 2-thienyl sulfides. a) From the organomagnesium compound. With cooling in ice, 7.4 g of dry, finely ground sulfur was added to 2-ethyl-5-thienylmagnesium bromide, prepared from 43.5 g of 5-bromo-2-ethylthiophene and 6.6 g of activated magnesium in 100 ml of ether. The mixture was boiled for 45 minutes, then 39.4 g of dry ethyl iodide added with cooling in ice; boiling was continued for an additional 1.5 hours. The mixture was left overnight under nitrogen and, on the following day, after 4 hours boiling, it was treated with 100 ml of 25% ammonium chloride solution with cooling. The ether layer was separated, washed 3 times with 0.5 N KOH solution and water, the ether removed and the residue steam distilled. After separation from the water and drying, the ethyl 5-ethyl-2-thienyl sulfide distilled at 109-110° (14 mm); $n^{20}D$ 1.5547, weight 15.9 g (50.5%). After a second vacuum distillation,the sulfide had the following constants.

B.p. 102-103° (10 mm), d^{20}_4 1.0577, $n^{20}D$ 1.5539, MR_D 51.98; calc. 52.02.

Found %: C 55.59, 55.65; H 6.80, 6.87; S 37.69, 37.57. $C_8H_{12}S_2$.

Calculated %: C 55.76; H 7.02; S 37.22.

The acetyl derivative obtained from this sulfide (see below) melted at 47.5-48° after recrystallization from heptane.

Similarly, from 2-bromothiophene we obtained methyl 2-thienyl sulfide (48% yield) with b.p. 180-184°, $n^{25}D$ 1.5940 (b.p. 182° [9], $n^{25}D$ 1.5978 [15]).

TABLE 1

Alkyl Thienyl Sulfides

Starting compound and alkyl halide	Amt. of C_4H_9Li (moles)	Sulfide obtained	Yield (%)	Boiling point pressure (mm)	d	n_D	MR_D found	MR_D calc.	Найдено (%) C	H	S	Вычислено % C	H	S
Thiophene, CH_3I	0.834	Methyl 2-thienyl sulfide	81**	66—67° (10)	1.1752	1.5940	37.60	38.16	46.15, 46.30	4.63, 4.59	49.18, 49.44	46.11	4.64	49.24
Thiophene, C_2H_5I	1	Ethyl 2-thienyl sulfide	72	69 (7)	1.1230	1.5721	42.27	42.78	50.03, 50.16	5.52, 5.64	44.09, 44.30	49.95	5.59	44.46
2-Methylthiophene CH_3I	1	Methyl 5-methyl-2-thienyl sulfide	79	78—79 (10)	1.1254	1.5767	42.47	42.78	50.32, 50.34	5.63, 5.56	43.97, 43.81	49.95	5.59	44.46
2-Ethylthiophene, C_2H_5I	1	Ethyl 5-ethyl-2--thienyl sulfide***	74	103—105 (10)	—	1.5528	—	—	—	—	—	—	—	—
Thiophene, CH_3I	2	1) Methyl 2-thienyl sulfide 2) 2,5-Bis-(methyl-mercapto)-thio-phene	58 27	65—70 (10) 126—127 (10)	— 1.2291	1.5729*** 1.6248	— 51.35	— 51.98	— 41.29, 41.32	— 4.57, 4.61	— 54.50, 54.42	— 40.87	— 4.57	— 54.56

* The atomic refraction of the thiophene sulfur was taken as 6.81 and that of the sulfide sulfur as 9.20 [16].

** Calculated on n-butyllithium.

*** The acetyl derivative had m.p. 47–47.5°. A mixed melting point with the acetyl derivative of the sulfide obtained through the organo-magnesium compound was not depressed.

**** The refractive index was low due to the presence of methyl butyl sulfide.

TABLE 2

Acetyl Derivatives of Alkyl Thienyl Sulfides

Substance acetylated	Acylating agent	Catalyst	Acetyl derivative	Yield (%)	Melting point	Found (%)			Calc. (%)		
						C	H	S	C	H	S
Methyl 2-thienyl sulfide	CH_3COCl	$SnCl_4$	5-Methylmercapto-2-acetothienone*	39.5	53° (52—53[17])	48.85, 49.00	4.67, 4.63	37.30, 37.36	48.80	4.68	37.23
Methyl 5-methyl-2-thienyl sulfide			2-Methylmercapto-5-methyl-3-acetothienone	90	97	51.39, 51.33	5.38, 5.37	34.38, 34.08	51.57	5.41	34.42
Ethyl 5-ethyl-2-thienyl sulfide			2-Ethylmercapto-5-ethyl-3-acetothienone**	86.5	47.5—48	56.17, 56.33	6.60, 6.69	29.96, 30.10	56.03	6.58	29.92
2,5-Bis-(methylmercapto)-thiophene			2,5-Bis(methylmercapto)-3-acetothienone	29	74.5—75	44.12, 44.23	4.64, 4.68	43.81, 43.39	44.00	4.62	44.05
Methyl 2-thienyl sulfide	$(CH_3CO)_2O$	H_3PO_4	1) 5-Methylmercapto-2-acetothienone***	56.2	53	—	—	—	—	—	—
			2) 5-Methylmercapto-2,4-diacetylthiophene	very little	122	50.55, 50.68	4.91, 4.70	29.82, 29.47	50.44	4.70	29.92
2,5-Bis-(methylmercapto)-thiophene	$(CH_3CO)_2O$ 2 moles		2,5-Bis-(methylmercapto)-3-acetothienone	45.5	74—74.5	—	—	—	—	—	—

* Oxime, m.p. 97°. Found % N 7.38, 7.16. Calculated % N 7.48.

** Semicarbazone, m.p. 165—165.8°. Found % N 15.34, 15.30. Calculated % N 15.49.

*** B.p. 112—114° (2 mm).

b) From the organolithium compound. To an ether solution of thiophene or alkyl thiophene (1 mole) was added an ether solution of butyllithium (1 mole) with cooling; the mixture was boiled for about 2 hours. After the introduction of sulfur (1 mole) and alkyl halide (1.1 mole) (see point a), the mixture was boiled for 6-7 hours and treated, as described above. The sulfide obtained was vacuum distilled (the last time over metallic sodium) until the refractive index was constant (see Table 1).

Acetylation of alkyl thienyl sulfides. a) In the presence of stannic chloride. To a solution of sulfide (1 mole) in a tenfold amount of dry benzene by weight, was added acetyl chloride (1.1 mole) and at +4°, a solution of stannic chloride (1 mole) in benzene. After the $SnCl_4$ had been added, the coolant was removed and stirring was continued at room temperature for 1 hour. The mixture was then treated with dilute hydrochloric acid (1:9), and the benzene layer washed with water and dried with magnesium sulfate. The residue, after removal of the solvent, was steam distilled or, if it was a crystalline mass, it was recrystallized from ligroine, heptane, or alcohol.

b) In the presence of orthophosphoric acid. To a mixture of sulfide (1 mole) and acetic anhydride (1.1 mole) heated to 70°, was added crystalline orthophosphoric acid (0.05 mole) and the mixture heated on a boiling water bath for 1-2 hours. Water was then added to the cooled mixture and, after 30 minutes stirring, the heavy oil was separated; the aqueous layer was neutralized with sodium carbonate, extracted with ether, and the extract added to the oil. The solution obtained was washed with $NaHCO_3$ solution and water, and dried with magnesium sulfate; the ether was removed and the residue steam distilled, distilled in vacuum, or purified by recrystallization with charcoal (see Table 2).

2-Ethylmercapto-5-ethyl-3-thiophenecarboxylic acid. To 9.2 g of 2-ethylmercapto-5-ethyl-3-acetothienone and 30 ml of dry pyridine, was added 11.6 g of iodine, and after being heated for 30 minutes on a water bath, the solution was left overnight. On the following day, the pyridine was removed in vacuum and the residue boiled for 1 hour with 9 g of NaOH in 450 ml of 50% alcohol. The cooled solution was diluted with an equal volume of water and acidified with 10% hydrochloric acid. The precipitated carboxylic acid was collected by filtration and its ether solution washed with hyposulfite solution and water, and dried with magnesium sulfate. We obtained 6.1 g (65.7%) of acid, which melted at 127.5-128° after recrystallization from heptane and 50% alcohol.

Found %: C 49.85, 49.78; H 5.48, 5.40; S 28.90, 28.99. $C_9H_{12}O_2S_2$.

Calculated %: C 49.97; H 5.59; S 29.65.

Reductive desulfurization of 5-methylmercapto-2-acetothienone. 8.1 g of ketone, 480 ml of 95% alcohol, and about 80 g of Raney nickel were boiled for 2 hours. After this, a test for sulfur on the filtrate was negative. The precipitate was collected by filtration and extracted in a Soxhlet apparatus for 8 hours. The alcohol was distilled off from a flask with a large reflux head, and the residue was diluted with water and extracted with ether. After removal of the ether, 3.5 g of a mixture of aliphatic alcohol and ketone remained, and this was dissolved in 80 ml of glacial acetic acid and treated with 7 g of chromium trioxide at 25-30° for 2 hours. The mixture obtained was poured onto ice, neutralized with sodium carbonate, and extracted with ether. The ether solution was washed with water and sodium bicarbonate solution, and dried with magnesium sulfate. The ether solution yielded 0.8 g of hexanone-2 with b.p. 126-127°, $n^{20}D$ 1.3990 and 0.55 g of dodecanedione-2,11, which melted at 68-68.5° after recrystallization from heptane.

Found %: C 72.40, 72.35; H 10.97, 10.96. $C_{12}H_{22}O_2$.

Calculated %: C 72.68; H 11.00.

The hexanone-2 yielded a semicarbazone, which melted at 124° after recrystallization from 50% alcohol, acetone, and ethyl acetate.

Found %: C 53.41, 53.66; H 9.63, 9.62; N 26.46, 26.33. $C_7H_{15}ON_3$.

Calculated %: C 53.48; H 9.81; N 26.73.

A mixed melting point with this semicarbazone and that obtained from an authentic sample of hexanone-2 was not depressed. The following constants are given in the literature for hexanone-2.

B.p. 127.2° (760 mm), $n^{20}D$ 1.40072 [18], semicarbazone, m.p. 123.5-124.5° [19], 126° [18]; for dodecanedione-2,11 m.p. 69° [20].

Reductive desulfurization of 2-ethylmercapto-5-ethyl-3-thiophenecarboxylic acid. A solution of 5.9 g of acid in 10% Na_2CO_3, 350 ml of distilled water, and about 50 g of Raney nickel was stirred and heated for 2.5 hours at 80-90°. After this, a test for sulfur on the filtrate was negative. The precipitate was removed by filtration and the filtrate acidified and extracted with benzene. The precipitate was dissolved in conc. HCl and extracted with benzene. The benzene extracts were combined, washed thoroughly with water, and dried with magnesium sulfate. The benzene solution yielded 2.3 g of methylbutylacetic acid with b.p. 123-125° (30 mm), from which the acid chloride was prepared by the action of thionyl chloride and then the amide. After recrystallization from heptane and water, the amide melted at 68.5-69°.

Found %: C 64.83, 64.84; H 11.49, 11.37; N 10.84, 10.63. $C_7H_{15}ON$.

Calculated %: C 65.07; H 11.70; N 10.84.

In the literature, m.p. 70-72.5° is reported for the amide of methylbutylacetic acid, and m.p. 102.5-103.5° for the amide of ethylpropylacetic acid [21].

3-Bromo-5-ethylmercapto-2-ethylthiophene. To a mixture of 5.2 g of ethyl 5-ethyl-2-thienylsulfide, 40 ml of ether and 12 ml of conc. HCl at 10-15° was added 75 ml of an aqueous bromide-bromate solution with a bromine concentration of 64 g/liter over a period of 2 hours with stirring. After being stirred for 30 minutes, the mixture was worked up in the usual way to yield 6.3 g (84%) of a colorless substance, which distilled at 100-109° (2 mm), $n^{20}D$ 1.5805. After three distillations, the product had b.p. 105° (2 mm), $n^{20}D$ 1.5862.

Found %: C 38.38, 38.37; H 4.21, 4.26. $C_8H_{11}BrS_2$.

Calculated %: C 38.25; H 4.41.

2-Ethylmercapto-5-ethyl-3-thiophenecarboxylic acid. To a solution of 4.2 g (0.017 mole) of 3-bromo-5--ethylmercapto-2-ethylthiophene in 40 ml of dry ether at 0° was added 0.018 mole of n-butyllithium in ether. After 15 minutes stirring, the yellow solution was poured into a mixture of dry ice and ether. After evaporation of the carbon dioxide, 20 ml of water was added with cooling. The aqueous layer was separated and heated with charcoal. Acidification yielded 2.0 g (55.5%) of a colorless acid which melted at 126-127° after recrystallization fromheptane. A mixed melting point with a sample of the acid obtained by oxidation of the acetyl derivative (see above) was not depressed .

Acetylation of 5-bromo-2-ethylthiophene. 7.7 g of 5-bromo-2-ethylthiophene was acetylated in benzene with an equivalent amount of acetyl chloride in the presence of stannic chloride (see above). The usual processing and vacuum distillation yielded two fractions: 1st, b.p. 74-95° (2 mm), 4.2 g; 2nd, b.p. 95-100° (2 mm), 1.5 g. The latter fraction, which distilled with decomposition, crystallized on cooling and contained bromine. After recrystallization from n-octane, the substance melted at 37-37.5° and its composition corresponded to 5-bromo-2--ethyl-3 (or 4)- acetothienone.

Found %: C 41.50, 41.58; H 3.86, 3.85. C_8H_9OBrS.

Calculated %: C 41.21; H 3.90.

A semicarbazone was prepared from the first fraction, and this was recrystallized from acetone and alcohol, when it did not contain halogen and melted at 210-211° (with decomp.) on rapid heating.

Found %: C 51.11, 50.99; H 6.19, 6.09; S 15.16, 15.10. $C_9H_{13}ON_3S$.

Calculated %: C 51.16; H 6.20; S 15.18.

The literature reports for 5-ethyl-2-acetylthiophene b.p. 125.5° (16 mm) [13], and for the semicarbazone, m.p. 210-211.5° [6].

SUMMARY

1. A method was developed for preparing alkyl thienyl sulfides from lithium derivatives of thiophene and its homologs.

2. An investigation was made of the acetylation of alkyl thienyl sulfides in the presence of stannic chloride and orthophosphoric acid. It was shown that the acetyl group enters the position ortho to the sulfide group when both α-positions of the thiophene are occupied and in position 5 in alkyl 2-thienyl sulfides.

3. It was shown that for the preparation of compounds of the aliphatic series, corresponding to 3-substituted thiophenes, by hydrogenolysis of the latter, the method of protecting the α-position of the thiophene nucleus with activating alkylmercapto groups is extremely convenient.

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CARBON CHAIN POLYMERS AND COPOLYMERS

XIII. SYNTHESIS AND POLYMERIZATION OF SOME UNSATURATED COMPOUNDS CONTAINING ELEMENTS OF GROUP IV

G. S. Kolesnikov and S. L. Davydova

Institute of Heteroorganic Compounds, Academy of Sciences, USSR

Original article submitted May 24, 1958

The purpose of the present work was the preparation and polymerization of unsaturated heteroorganic compounds containing Sn, Ge, and Si in their structure, namely vinyl and styryl derivatives of the type $R_3MCH=CH_2$ and $R_3MC_6H_4CH=CH_2$. Triethylvinylsilane was obtained for the first time by Ushakov and Itenberg [1] by dehydrochlorination of triethyl-β-chloroethylsilane: a more detailed investigation of this compound and its analogs was made by Kanazashi, who obtained them by the interaction of trialkylchlorosilanes, vinyl bromide, and Na [2]. We synthesized trimethylvinylsilane by the reaction of vinylmagnesium bromide with trimethylchlorosilane and triethylvinylstannane, according to Seyferth and Stone's method [3], by the reaction of vinylmagnesium bromide with triethylchlorostannane, and we obtained triethylvinylgermane for the first time by the reaction of triethyl-bromogermane with vinylmagnesium bromide (di-, tri-, and tetravinyl derivatives of germane are described in the literature [4,5]). We also synthesized trichlorovinylgermane by the scheme of Petrov et al. [6], but, using as the starting material tribromoethylgermane, which was obtained by direct synthesis from ethyl bromide and metallic germanium in the presence of reduced copper. It is interesting to note that in the reaction of tribromoethyl-germane with sulfuryl chloride in the presence of benzoyl peroxide, together with chlorination of the ethyl group, there was complete replacement of the bromine by chlorine and, as a result, the reaction yielded trichloro-α--chloroethyl- and trichloro-β-chloroethylgermane; dehydrochlorination of the latter with quinoline proceeded normally and led to the formation of trichlorovinylgermane [6].

In analogy with the preparation of 4-trialkylsilylstyrenes by dehydration of appropriate phenylmethylcarbinols [7,8], we attempted to synthesize trialkylstannyl- and germanyl derivatives of styrenes. The reaction of 4-triethylstannylphenylmagnesium bromide and acetaldehyde yielded 4-triethylstannylphenylcarbinol, the reaction of 4-triethylgermanylphenylmagnesium bromide with acetaldehyde gave 4-triethylgermanylphenylcarbinol, and the reaction of ethylene oxide with 4-triethylgermanylphenylmagnesium bromide gave β-(4-triethylgermanylphenyl)--ethyl alcohol. Since attempts to dehydrate these alcohols were unsuccessful, for synthesizing the substituted styrenes, we used the method of Kharasch [9] and prepared 4-triethylstannylstyrene from 4-triethylstannylphenyl-magnesium bromide and vinyl bromide in the presence of anhydrous cobalt salts; 4-triethylgermanylstyrene and 4-trimethylsilylstyrene were obtained analogously.

We attempted to obtain polymers from the unsaturated compounds synthesized. As polymerization initiators and catalysts we tested titanium tetrachloride, a mixture of triethylaluminum, and titanium tetrachloride, triiso-butylboron, boron trifluoride, and the diacid fluoride of butylboric acid; polymerization was carried out in block and in solution. The yields in the polymerizations were insignificant and did not exceed 3.4% (4-triethylstannyl-styrene); the most efficient catalyst was found to be titanium tetrachloride (solvent methylene chloride, temperature −50°). The low yields of polymerization product may be explained by steric hindrance to the polymerization reaction caused by the large volume of the R_3M- and $R_3MC_6H_4$- groups, as was proposed by Kanazashi [2] for the analogous compounds of silicon.

Triethylvinylgermane. To vinylmagnesium bromide (from 13.5 g of vinyl bromide and 3 g of magnesium in 50 ml of absolute tetrahydrofuran) was added 24 g of triethylbromogermane [10] in 50 ml of the same solvent, when the evolution of heat was observed. The reaction mixture was boiled for 5 hours, cooled, and decomposed with ammonium chloride solution, the organic layer separated, the aqueous layer extracted with ether, the ether extract added to the organic layer and dried, the solvent removed, and the residue vacuum distilled. We obtained 6.7 g (35.5%) of triethylvinylgermane with b.p. 151-152° at 748 mm and 40.0° at 4 mm, $n^{20}D$ 1.4518.

Found %: C 51.99, 52.17; H 9.76, 9.80; Ge 37.92, 38.00. $C_8H_{18}Ge$.

Calculated %: C 51.43; H 9.76; Ge 38.86.

Triethylvinylstannane [3] was obtained analogously from 25.0 g of vinyl bromide, 6.5 g of magnesium, and 28 g of triethylchlorostannane in 150 ml of absolute tetrahydrofuran. We isolated 11.92 g (46.0%) of triethylvinyl-stannane with b.p. 53-54° at 7 mm, $n^{20}D$ 1.4809.

Trimethylvinylsilane was obtained analogously from 53.5 g of vinyl bromide, 12.5 g of magnesium, and 27 g of trimethylchlorosilane in 250 ml of absolute tetrahydrofuran. We isolated 9.44 g (24.8%) of trimethylvinyl-silane with b.p. 53-54° at 757 mm, $n^{20}D$ 1.3878.

Triethyl-4-bromophenylgermane [11]. 24 g of triethylbromogermane in absolute tetrahydrofuran was added to a solution prepared from 5 g of magnesium and 48 g of p-dibromobenzene in the same solvent. The reaction mixture was heated for 2 hours, cooled, and decomposed with ammonium chloride solution, the organic layer separated, the aqueous layer extracted with ether, the ether extract added to the organic layer and dried, the solvent removed, and the residue vacuum distilled. We obtained 11.2 g (46.6%) of triethyl-4-bromophenylgermane with b.p. 126-129° at 5 mm, $n^{20}D$ 1.5560.

We also isolated 14.4% of the original p-dibromobenzene.

Found %: C 45.15, 44.99; H 5.70, 5.86. $C_{12}H_{19}GeBr$.

Calculated %: C 45.64; H 6.02.

β-(4-Triethylgermanylphenyl)-ethyl alcohol. To the organomagnesium compound prepared from 15 g of triethyl-4-bromophenylgermane and 1.4 g of magnesium in absolute ether was added a solution of 2.64 g of ethylene oxide in ether, the mixture heated for 3 hours and then worked up in the usual way on the following day. We obtained 5.7 g (42.5%) of β-(4-triethylgermanylphenyl)-ethyl alcohol with b.p. 95-97° at 5 mm, $n^{20}D$ 1.5155.

Found %: C 59.66, 59.80; H 8.35, 8.38. $C_{14}H_{24}GeO$.

Calculated %: C 59.87; H 8.55.

4-Triethylgermanylphenylmethylcarbinol was obtained analogously to the previous compound from 15 g of triethyl-4-bromophenylgermane, 1.4 g of magnesium, and 2.64 g of acetaldehyde. We obtained 3.84 g of carbinol (19.6%) with b.p. 92.5-93° at 5 mm, $n^{20}D$ 1.5170.

4-Triethylstannylphenylmethylcarbinol was obtained similarly to the previous compound from 42.5 g of triethyl-4-bromophenylstannane [11], 3.1 g of magnesium, and 5.7 g of acetaldehyde in 150 ml of absolute ether. The reaction mixture was kept at −10° for 2 hours and at room temperature for 1 hour, and then poured onto 100 g of ice; if a stable emulsion formed, 1% sulfuric acid solution was added. By the usual method, the ether solution yielded 5.7 g (14.9%) of carbinol with b.p. 112-114° at 4 mm, $n^{20}D$ 1.5422.

Found %: C 51.76, 51.52; H 6.92, 6.90; Sn 36.79, 36.89. $C_{14}H_{24}SnO$.

Calculated %: C 51.72; H 7.39; Sn 36.29.

Attempts to dehydrate the above carbinols by heating with phosphorus pentoxide in benzene or in the presence of potassium bisulfate under reduced pressure were unsuccessful; although dehydration occurred over aluminum oxide at 300-320° at a pressure of 150 mm, it was impossible to isolate the dehydration products in a pure form.

4-Triethylstannylstyrene. To a solution of the organomagnesium compound prepared from 49.5 g of triethyl--4-bromophenylstannane (b.p. 150-151° at 6 mm, $n^{20}D$ 1.5628) and 4.4 g of magnesium in 150 ml of absolute

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*Carried out with the help of L. A. Gavrikova and L. M. Soskova.

ether was added 0.88 g of anhydrous cobalt chloride with cooling to −10° and the reaction mixture was kept in a stream of nitrogen until it darkened considerably. Then, with strong cooling, 29.4 g of vinyl bromide was added, and the reaction mixture kept at room temperature for 12 hours, heated for 0.5 hours, cooled, and poured into a mixture of 100 g of ice, 200 ml of water, and 10 ml of glacial acetic acid. The ether layer was washed with 5% sodium bicarbonate solution and dried, and by the usual method it yielded 10.8 g (24.2%) of 4-triethylstannylstyrene with b.p. 100-102° at 4 mm, $n^{20}D$ 1.5388.

Found %: C 54.37, 54.50; H 7.06, 7.00; Sn 37.76, 37.81. $C_{14}H_{22}Sn$.

Calculated %: C 54.44; H 7.17; Sn 38.41.

4-Triethylgermanylstyrene was obtained analogously to the previous compound from 21.8 g of triethyl-4-bromophenylgermane (b.p. 126-129° at 5 mm, $n^{20}D$ 1.5560), 1.7 g of magnesium, 0.45 g of anhydrous cobalt chloride, and 14.8 g of vinyl bromide in 100 ml of absolute ether. The yield of 4-triethylgermanylstyrene was 4.8 g (26.4%) with b.p. 95.5-96.5° at 6 mm, $n^{20}D$ 1.5192.

Found %: Ge 27.81, 28.34. $C_{14}H_{22}Ge$.

Calculated %: Ge 27.64.

4-Trimethylsilylstyrene was synthesized analogously to the previous compound from 54 g of trimethyl-4-bromophenylsilane (b.p. 126-128° at 20 mm, $n^{20}D$ 1.5340), 5.8 g of magnesium, 1.6 g of anhydrous cobalt chloride, and 51 g of vinyl bromide in 200 ml of absolute ether. We obtained 4.0 g (9.6%) of 4-trimethylsilylstyrene with b.p. 103° at 22 mm, $n^{20}D$ 1.5236. According to literature data, the b.p. is 101-101.5° at 20 mm, $n^{20}D$ 1.5221 [8].

SUMMARY

A series of unsaturated compounds of germanium, tin, and silicon were synthesized and, of these, triethylvinylgermane, 4-triethylgermanylstyrene, and 4-triethylstannylstyrene were described for the first time.

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ARYLPHENAZINES. 1-PHENYLPHENAZINE AND ITS DERIVATIVES

Yu. S. Rozum

Institute of Organic Chemistry, Academy of Sciences, UkrSSR

Original article submitted May 22, 1958

In a previous communication, 2-phenylphenazine and some of its derivatives were described [1]. In connection with searches for new antitubercular preparations, analogs of pyocyanine, in the present article a description is given of 1-phenylphenazine, its chloro and methoxy derivatives, the N-monoxides, quaternary salts of the bases, and quaternary salts of the N-monoxides.

The base and N-monoxide of 1-phenylphenazine were obtained by an alkaline condensation according to Wohl's method [2] of o-nitrodiphenyl with appropriate amines (aniline, anisidine, and chloroaniline), or of o-aminodiphenyl with aromatic nitro derivatives (nitrobenzene, nitrochlorobenzene, and nitroanisole). For example, 1-phenylphenazine was obtained from o-nitrodiphenyl and aniline, or o-aminodiphenyl and nitrobenzene by the scheme:
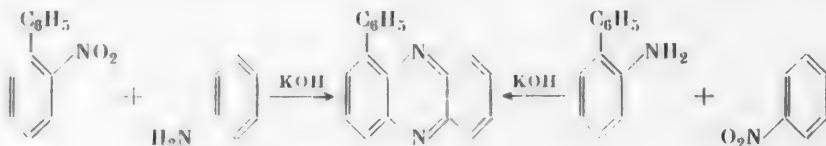
o-Nitrodiphenyl and p-anisidine were condensed for the preparation of 1-phenyl-7-methoxyphenazine. In the condensation of o-nitrodiphenyl with o-anisidine, elimination of the methoxy group occurred with the formation of a considerable amount of 1-phenylphenazine instead of the 1-phenyl-5-methoxyphenazine expected. A similar phenomenon was observed by Serebryanyi and Il'yushina [3] in preparing alkoxyphenazines from aromatic nitro compounds and o-anisidine by Wohl's method. If the nitro component was used in excess in the condensation, then together with the phenazine base, the N-monoxide of the latter was also formed. It is known [4] that in the formation of N-monoxides of phenazine the oxygen atom is derived from the nitro group of the aromatic nitro compound used in the condensation. On the basis of this, we expected to obtain the 9-oxide of 1-phenylphenazine by the scheme presented above from o-nitrodiphenyl and aniline. For this purpose, a considerable excess of the nitro compound was introduced into the condensation. Only 1.3% of the expected phenazine oxide was isolated. Due to steric hindrance from the phenyl group, the reaction proceeded toward the formation of 1-phenylphenazine, of which 18% was isolated in the experiment described. However, in the condensation of o-nitrodiphenyl with p-anisidine, a yield of 11.4% of the 9-oxide of 1-phenyl-7-methoxyphenazine was obtained. In this case, the formation of the 9-oxide was promoted by conjugation of the OCH_3 group with the nitrogen atom at position 9, which was reported previously [5]. As a result of the absence of steric hindrance, the reaction of o-aminodiphenyl with nitrobenzene gave the 10-oxide of 1-phenylphenazine in a considerable yield.

1-Phenyl- and 1-phenyl-7-chlorophenazines were pale yellow, crystalline compounds; the methoxy derivatives had a bright yellow color. In chloroform under a quartz lamp, the N-monoxides gave a clear blue fluorescence which disappeared when the N-oxide was reduced. The phenylphenazines were converted into colorless dihydrophenylphenazines in glacial acetic acid with zinc dust. In concentrated sulfuric acid, 1-phenylphenazine and its derivatives formed solutions of green disalts, which changed to red solutions of monosalts on partial hydrolysis and then the bases crystallized as pale yellow needles on complete hydrolysis.
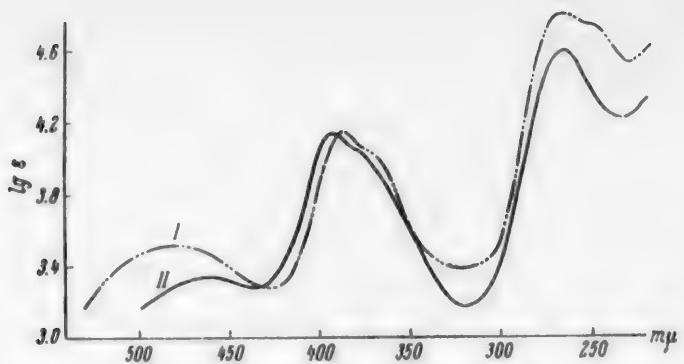
Fig. 1. I) 1-Phenyl-10-methylphenazinium perchlorate; II) 1-
-phenyl-9-methylphenazinium perchlorate. Concentration of
substance $2.5 \cdot 10^{-5}$ M.
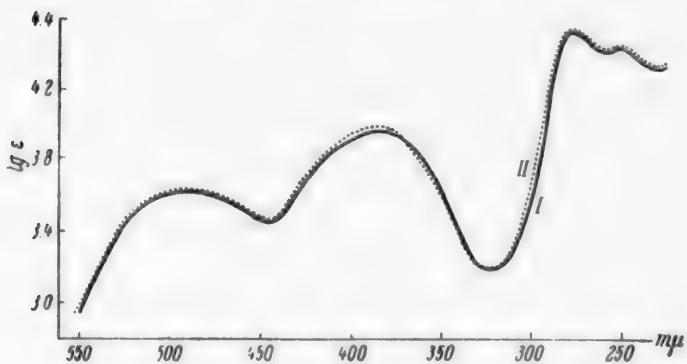
Fig. 2. I) 1-Phenyl-7-methoxy-10-methylphenazinium perchlor-
ate; II) 1-phenyl-7-methoxy-N-methylphenazinium perchlorate.
Concentration of substance $4 \cdot 10^{-5}$ M.
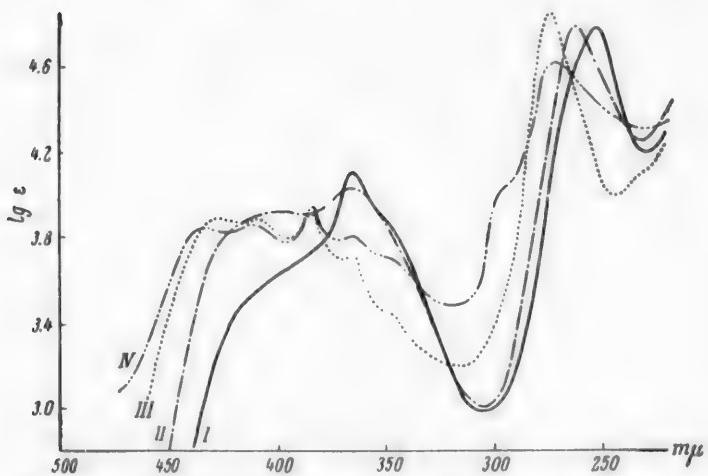
Fig. 3. I) 1-Phenylphenazine; II) 1-phenyl-7-methoxyphenazine;
III) 9-oxide of 1-phenylphenazine; IV) 10-oxide of 1-phenylphen-
azine. Solvent — alcohol; concentration of all substances: $25 \cdot 10^{-5}$ M.

The quaternary salts of 1-phenylphenazine N-oxides were obtained by the method we described previously [6], by the action of dimethyl sulfate on the N-monoxide in nitrobenzene; the salts of the bases themselves were obtained by careful reduction of the quaternary salts of the N-monoxides with zinc dust in water.

Due to weakening of the basicity of the azine ring by the introduction of the phenyl radical, with the arylated phenazines, the formation of quaternary salts proceeded with more difficulty than with the corresponding alkyl and alkoxy derivatives of phenazine. For example, the quaternary salts of 1- or 2-methylphenazine were formed when the bases were heated with dimethyl sulfate in nitrobenzene for 3 minutes at 90-95°. Quaternary salts of 1- or 2-phenylphenazines were not formed under the same conditions.

Dimethyl sulfate reacted readily with 1-phenylphenazine in nitrobenzene over a period of 8 minutes at 125-130° to give a quantitative yield of a quaternary salt in which the alkyl had added to the nitrogen atom in position 10. This salt was identified with a standard prepared from the 9-oxide of 1-phenylphenazine by the scheme:
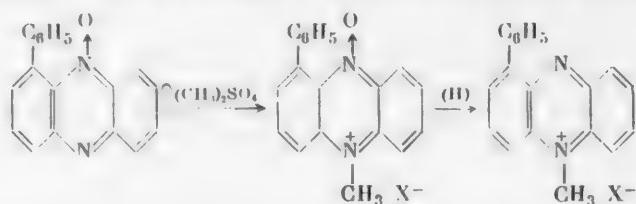
The two salts (as the perchlorates) had identical melting (214°) and decomposition (217°) points and a mixture of them melted and decomposed without depression. The absorption spectra of the salts coincided completely; the maxima of the absorption bands lay at 250 (inflection), 267, 387, and 482 mμ. The absorption curve is illustrated in Fig. 1, I.

Under the given conditions, the isomeric salt with the methyl on the nitrogen atom at position 9 was not formed, probably due to the proximity of the phenyl group and its attraction of electrons from the nitrogen atom at position 9. However, if position 10 was occupied by oxygen, as in the 10-oxide of 1-phenylphenazine, for example, heating a mixture of the latter with dimethyl sulfate at 135-140° for 20 minutes formed a quaternary salt of the 10-oxide of 1-phenylphenazine in which the alkyl had added to the nitrogen atom in position 9. By reduction of this with zinc dust in water, we obtained a second standard, the isomeric quaternary salt 1-phenyl--9-methylphenazinium perchlorate, whose spectrum is illustrated in Fig. 1, II.

The action of dimethyl sulfate on 1-phenyl-7-methoxyphenazine yielded a 1-phenyl-7-methoxy-N-methylphenazinium salt. Judging by the melting and decomposition points (239°) and the absorption spectra [250 (inflection), 277, 382, and 490 mμ], the preparation obtained was identical with the salt prepared from the 9-oxide of 1-phenyl-7-methoxyphenazine by the scheme presented above, i.e., it was a 1-phenyl-7-methoxy-10-methylphenazinium salt (Fig. 2, I, II). The yield of this salt was less than in the case where the phenyl group was the only substituent in the phenazine nucleus. This apparently depended on the different orienting effects of the phenyl in position 1 and the methoxy group in position 7 when they were present together. These effects were noticeable from the absorption spectra: 1-phenylphenazine, like unsubstituted phenazine, had two narrow absorption bands with maxima at 252 and 365 mμ in alcohol solution (Fig. 3, I). The presence of an OCH$_3$ group at position 7 in the 1-phenylphenazine molecule shifted the shortwave band of 1-phenylphenazine toward longer wavelengths by 10 mμ, and in the longwave region, a new band appears with a maximum at 400 mμ in the stretching position (Fig. 3, II).

How the absorption spectra of the N-oxides of 1-phenylphenazine changed may be followed from the absorption curves illustrated in Fig. 3, III and IV.

EXPERIMENTAL*

1-Phenylphenazine. 139 g of o-nitrodiphenyl, 46 g of aniline, 120 g of powdered KOH, and 500 ml of benzene were boiled for 18 hours with stirring. The benzene layer was decanted and the residue washed 3 times with hot benzene. The combined benzene solutions were washed free from alkaline components with water and

*I. B. Grebenyuk and A. A. Kasilenko helped with the experimental part of the work.

steam distilled. The residue after steam distillation was dissolved in 300 ml of benzene and extracted with concentrated hydrochloric acid. The precipitated acid salt was collected by filtration and decomposed with ammonia. The reaction products were purified and separated by chromatography on aluminum oxide (column 600 × 50 mm). The second from bottom zone yielded 23.3 g (18%) of 1-phenylphenazine. The yellow needles had m.p. 157° (from alcohol). They dissolved in benzene and chloroform, and were insoluble in water and difficultly soluble in ligroine. They did not fluoresce under a UV lamp. The absorption maxima were at 252 and 365 mμ.

Found %: N 10.99, 11.07. $C_{18}H_{12}N_2$.

Calculated %: N 10.95.

1-Phenylphenazine 9-oxide was isolated from the third zone of the chromatogram of the previous experiment. The lustrous, olive-colored plates had m.p. 172° (decomp.). The yield was 1.8 g (1.3%). The product did not fluoresce under a UV lamp. The absorption maxima were at 279, 364, 382, 406, and 426 mμ.

Found %: N 10.05, 10.09. $C_{18}H_{12}ON_2$.

Calculated %: N 10.29.

1-Phenylphenazine 10-oxide. 95 g of o-aminodiphenyl, 92 g of nitrobenzene, 120 g of powdered KOH, and 350 ml of benzene were boiled for 16 hours. The reaction mixture was treated similarly to the previous one. From the second zone of the chromatogram we isolated 0.9 g (0.6%) of 1-phenylphenazine. From the third zone we isolated 8 g (5.2%) of 1-phenylphenazine 10-oxide, which fluoresced strongly under a UV lamp. The oxide isolated from the eluate was collected by filtration, washed with ligroine on the filter for purification, and again recrystallized from benzene. The bright yellow plates had m.p. 191° and decomp. point 200-202°. In concentrated sulfuric acid, the monosalt had a red color. The absorption maxima of 1-phenylphenazine 10-oxide were at 270, 295, 364, 382, 410, and 430 mμ.

Found %: N 10.35, 10.15. $C_{18}H_{12}ON_2$.

Calculated %: N 10.29.

1-Phenyl-7-methoxyphenazine. 100 g of o-nitrodiphenyl, 50 g of p-anisidine, 60 g of powdered KOH, and 400 ml of benzene, were boiled for 16.5 hours. The reaction mixture was treated similarly to the previous one. From the third zone of the chromatogram we isolated 8 g (6.6%) of 1-phenyl-7-methoxyphenazine. The pale yellow needles had m.p. 166° (from alcohol). They were soluble in benzene and alcohol, with great difficulty in ligroine, and insoluble in water. The absorption maxima were at 261, 366, and 400 mμ.

Found %: N 9.56, 9.59. $C_{19}H_{14}ON_2$.

Calculated %: N 9.79.

1-Phenyl-7-methoxyphenazine 9-oxide was isolated from the fourth zone of the chromatogram from the previous experiment. The crystalline product gave off a bright orange light under a UV lamp. The yield was 13.8 g (11.4%). The yellow needles had m.p. 199° (decomp.). They were recrystallized from alcohol. The product was readily soluble in chloroform. A red monosalt was formed in concentrated sulfuric acid. The absorption maxima were at 247, 276, 365, 382, 421 and 445 mμ.

Found %: N 9.23, 9.14. $C_{19}H_{14}O_2N_2$.

Calculated %: N 9.27.

1-Phenyl-5-methoxyphenazine 9-oxide. 100 g of o-nitrodiphenyl, 50 g of o-anisidine, 120 g of powdered KOH, and 400 ml of benzene were boiled for 19 hours. The reaction mixture was processed as usual. From the second zone of the chromatogram we isolated 23.4 g (20.4%) of 1-phenylphenazine, formed as a result of elimination of the OCH$_3$ group. The m.p. was 157°. From the third zone, we isolated 10.7 g (7.5%) of 1-phenyl-5-methoxyphenazine 9-oxide. The yellow prisms had m.p. 206-207° (from xylene). The absorption maxima were at 266, 350, 364, and 418 mμ.

Found %: N 9.29, 9.18. $C_{19}H_{14}O_2N_2$.

Calculated %: N 9.27.

1-Phenyl-7-chlorophenazine was obtained as described above from 100 g of o-nitrodiphenyl and 51 g of p-chloroaniline in a yield of 4.7 g (3.8%). The base was extracted from the second zone of the chromatogram and luminesced weakly under a UV lamp. It was sparingly soluble in dilute acids. The yellow prisms had m.p. 188° (from o-xylene). The absorption maxima were at 257 and 370 mμ.

Found %: N 9.62, 9.79; Cl 12.20, 12.18. $C_{18}H_{11}N_2Cl$.

Calculated %: N 9.63; Cl 12.22.

1-Phenyl-10-methylphenazinium 9-oxide perchlorate. 0.54 g of 1-phenylphenazine 9-oxide was dissolved in 0.8 ml of nitrobenzene at 115°, 1 ml of dimethyl sulfate added, and the temperature kept at 120-125° for 20 minutes. The nitrobenzene and excess dimethyl sulfate were washed out with benzene and ether until the quaternary salt solidified as a red-brown precipitate, which was then dissolved in 5 ml of alcohol, treated with activated charcoal, and precipitated with sodium perchlorate. The yield was 0.33 g (43%). The red-brown prisms had m.p. 197° (decomp.). The product was recrystallized from 50% alcohol. The absorption maxima were at 260 and 387 mμ.

Found %: N 7.31, 7.41; Cl 9.17, 9.14. $C_{19}H_{15}O_5N_2Cl$.

Calculated %: N 7.24; Cl 9.18.

1-Phenyl-9-methylphenazinium 10-oxide perchlorate was obtained analogously to the one presented above from 0.68 g of 1-phenylphenazine 10-oxide in 1 ml of nitrobenzene with 1 ml of dimethyl sulfate at 135-140° for 20 minutes. The formation of the quaternary salt proceeded with difficulty. The yield was 0.7 g (72%). The red plates had m.p. 217° (decomp.). The product was recrystallized from 50% alcohol. The absorption maxima were at 251, 285, 398, and 502 mμ.

Found %: N 7.38, 7.49; Cl 9.26, 9.40. $C_{19}H_{15}O_5N_2Cl$.

Calculated %: N 7.24; Cl 9.18.

1-Phenyl-7-methoxy-10-methylphenazinium 9-oxide perchlorate was obtained similarly from 0.6 g of 1-phenyl-7-methoxyphenazine 9-oxide in 2.5 ml of nitrobenzene with 1.3 ml of dimethyl sulfate at 130-135° for 10 minutes. The yield was 0.4 g (50%). The product was recrystallized from 50% alcohol. The brownish red prisms had m.p. 228° (decomp.). The absorption maxima were at 262, 383, and 490 mμ.

Found %: N 6.85, 6.99; Cl 8.69, 8.73. $C_{20}H_{17}O_6N_2Cl$.

Calculated %: N 6.72; Cl 8.52.

1-Phenyl-5-methoxy-10-methylphenazinium 9-oxide perchlorate was obtained similarly from 0.6 g of 1--phenyl-5-methoxyphenazine 9-oxide in a yield of 0.35 g (44%). The lustrous brown plates had m.p. 175° and decomp. point 190° (from 50% alcohol). The absorption maxima were at 287 and 390 mμ.

Found %: N 6.64, 6.58; Cl 8.73, 8.78. $C_{20}H_{17}O_6N_2Cl$.

Calculated %: N 6.72; Cl 8.52.

1-Phenyl-9-methylphenazinium perchlorate. 0.65 g of the methylsulfate of 1-phenyl-9-methylphenazinium 10-oxide was dissolved in 10 ml of water and 0.5 g of zinc dust added at 18-20° with continuous stirring. Over a period of 3-4 minutes, the temperature rose to 31-32° due to an exothermal reaction. After 3 minutes, the reaction was complete, and its end was determined by the change in color of the quaternary salt solution. The original orange solution became dark yellow. The zinc dust was removed by filtration, and the quaternary salt precipitated by the addition of a few drops of a 10% solution of sodium perchlorate. The yield was 0.1 g (16%). The dark yellow needles had m.p. 180° and decomp. point 195-196°. The product was recrystallized from 50% alcohol. The absorption maxima were at 268, 394, and 460 mμ.

Found %: N 7.34, 7.19; Cl 9.57, 9.69. $C_{19}H_{15}O_4N_2Cl$.

Calculated %: N 7.55; Cl 9.58.

1-Phenyl-10-methylphenazinium perchlorate was obtained similarly from 0.31 g of the methylsulfate of 1-phenyl-10-methylphenazinium 9-oxide in a yield of 0.2 g (69%). The brownish orange needles had m.p. 214° and decomp. point 217° (from 50% alcohol). The absorption maxima were at 250 (inflection), 267, 387, and 482 mμ.

Found %: N 7.57, 7.73. $C_{19}H_{15}O_4N_2Cl$.

Calculated %: N 7.55.

1-Phenyl-7-methoxy-10-methylphenazinium perchlorate was obtained analogously from 0.6 g of 1-phenyl--7-methoxyphenazine 9-oxide, which was converted into the methylsulfate of 1-phenyl-7-methoxyphenazinium 9-oxide. The yield was 0.3 g (37%). The brown needles with a metallic luster had m.p. 238° (decomp.). The absorption maxima were at 250 (inflection), 278, 383, and 494 mμ.

Found %: N 6.98; Cl 9.06, 9.08. $C_{20}H_{17}O_5N_2Cl$.

Calculated %: N 6.99; Cl 8.86.

1-Phenyl-N-methylphenazinium perchlorate and methylsulfate. 2.56 g of 1-phenylphenazine was dissolved in 2.5 ml of nitrobenzene at 120°, 2.5 ml of dimethyl sulfate added, and the temperature raised to 125-130° and kept there for 8 minutes. The color of the reaction mixture was dark red. The nitrobenzene and excess dimethyl sulfate were washed out with ether. The residue was a red, viscid mass, which rapidly solidified. It crystallized from alcohol in the form of red plates. The yield before recrystallization from alcohol was 3.8 g (100%). The m.p. was 117° (decomp.) and the perchlorate had m.p. 214° and decomp. point 217°. The absorption maxima were at 250 (inflection), 267, 387, and 482 mμ. A mixture with 1-phenyl-10-methylphenazinium perchlorate melted at 213-214° and decomposed at 217°.

Found %: N 7.47, 7.38; Cl 9.60, 9.54. $C_{19}H_{15}O_4N_2Cl$.

Calculated %: N 7.55; Cl 9.58.

1-Phenyl-7-methoxy-N-methylphenazinium perchlorate and methylsulfate. 1.43 g of 1-phenyl-7-methoxy-phenazine was dissolved in 2 ml of nitrobenzene at 120°, 1.5 ml of dimethyl sulfate added, and the mixture heated for 5 minutes at 125-130°. At this temperature, the quaternary salt separated as a red, crystalline precipitate, which was washed with toluene and ether on the filter. The yield was 1.8 g (87%). The product was recrystallized from alcohol. The reddish brown plates had m.p. 182° (decomp.). The perchlorate formed red plates with m.p. 239° (decomp.); in reflected light, the crystals appeared as violet plates with a metallic luster. A mixture with 1-phenyl-7-methoxy-10-methylphenazinium perchlorate melted at 238° (decomp.). The absorption maxima were at 250 (inflection), 277, 382, and 490 mμ.

Found %: N 6.89, 6.99. $C_{21}H_{20}O_5N_2S$.

Calculated %: N 6.80.

Found %: Cl 8.98, 9.08. $C_{20}H_{17}O_5N_2Cl$.

Calculated %: Cl 8.86.

1-Phenyl-7-chloro-N-methylphenazinium perchlorate was obtained analogously to the previous compound from 1.5 g of 1-phenyl-7-chlorophenazine in 3 ml of nitrobenzene with 2.5 ml of dimethyl sulfate at 125-130° over a period of half an hour. The yield was 1.8 g (90%). The perchlorate formed orange plates with m.p. 216° (decomp.). The product was recrystallized from alcohol. The absorption maxima were at 255, 268, 380 (stretching), 394, and 484 mμ.

Found %: N 6.89, 6.85; Cl 17.54, 17.51. $C_{19}H_{14}O_4N_2Cl_2$.

Calculated %: N 6.91; Cl 17.53.

SUMMARY

A series of 1-phenylphenazine derivatives were synthesized, and their properties described. It was found that, in the reaction of dimethyl sulfate with 1-phenylphenazine, the methyl group added only to the nitrogen atom at position 10, forming a 1-phenyl-10-methylphenazinium salt. The second isomeric salt with the alkyl on the nitrogen atom at position 9 was obtained by an indirect method through the quaternary salt of 1-phenyl-phenazine 10-oxide. 1-Phenyl-7-methoxyphenazine gave an 85-87% yield of a quaternary salt in which the alkyl group added to the nitrogen atom at position 10.

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REDUCTION OF Δ^3-MENTHENE OXIDE WITH LITHIUM ALUMINUM HYDRIDE

G. V. Pigulevskii, S. A. Kozhin and D. V. Motskus

Leningrad State University

In 1957 [1], we published the results of an investigation of the catalytic hydrogenation of menthene oxides. It was established that the hydrogenation proceeded with great difficulty, and led to quite complex mixtures of products. Under the conditions we found, hydrocarbons, ketones, and other compounds were formed besides the alcohols expected. This compelled us to use a more suitable reducing agent for the conversion from oxides to the corresponding alcohols. As is known, steroid oxides [2], and also certain simpler oxides [3], are readily converted into alcohols by reduction with lithium aluminum hydride, and the reaction is not usually accompanied by the formation of side products. Only limonene monoxide [4] of the oxides of monocyclic terpenoid hydrocarbons has been reduced with lithium aluminum hydride.

The present article contains preliminary data, which we obtained by investigating the reduction of Δ^3-menthene oxide with lithium aluminum hydride.

The Δ^3-menthene oxide, which we used as the starting material, was obtained by oxidizing a mixture of Δ^3-menthene and p-menthane with perbenzoic acid. This mixture of hydrocarbons was prepared by partial hydrogenation of a mixture of Δ^3-menthene and Δ^2-menthene [5], which, in its turn, was obtained by thermal decomposition of menthyl acetate [5,6].

Δ^3-Menthene oxide was reduced with lithium hydride both under the usual conditions (at the boiling point of an ether solution), and under more drastic conditions (at elevated temperatures, and, finally, without solvent). It was found that under normal conditions the reduction of the oxide did not go to completion. The amount of aluminum hydride taken had hardly any effect on the final result: from 40 to 50% of the oxide did not react with an $LiAlH_4$ excess of from 100 to 485%, respectively. When the reaction was carried out under more drastic conditions, the Δ^3-menthene oxide was reduced completely.

The composition of the reduction products of Δ^3-menthene oxide also changed in relation to the reaction conditions. In all cases, the main reaction products were the corresponding alcohols: menthanol-4 and one of the stereoisomeric menthanols-3 of the neo series, in all probability, neoisomenthol. However, with reduction under normal conditions, the main product was menthanol-3 (about 70% calculated on the oxide reduced), while with reduction under drastic conditions, menthanol-3 (about 70%) predominated.

We characterized menthanol-4 by preparation of the phenylurethan with m.p. 95-96° [7]. The Raman spectra of the corresponding fractions of the reduction products had an intense line of ring pulsation with $\Delta\nu$ 708 cm^{-1}. Such a $\Delta\nu$ value for pulsation is characteristic of tertiary monocyclic alcohols of the terpene series [8].

To identify the secondary alcohol, formed by the reduction of Δ^3-menthene oxide, we prepared its p-nitrobenzoate with m.p. 55-55.5°, which, according to one of the literature sources [9], corresponds to the p-nitrobenzoate of DL-neoisomenthol. The spectrum of the corresponding fraction had an intense line with $\Delta\nu$ 760 cm^{-1}, characteristic of pulsations of the ring of secondary alcohols of the neo series [8].*

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* The spectrum of Δ^3-menthene also had a line with $\Delta\nu$ 760 cm^{-1}. However, the presence of the original oxide in the fraction investigated was excluded, since the boiling point of the oxide was considerably lower than the boiling point of the reduction products.

It should be noted that in all cases the reduction products also contained very small amounts (less than 10%) of another stereoisomer of menthanol-3 (menthol or isomenthol). Its presence was indicated by a line with $\Delta \nu$ 771 cm^{-1} [8] in the spectrum of the higher-boiling fraction of the reduction products, and the high optical activity of this fraction.

The results we obtained make it possible to put forward the hypothesis that Δ^3-menthene oxide is a mixture of stereoisomers, which may be readily reduced unequally by lithium aluminum hydride due to steric hindrance. Therefore, depending on the conditions, the composition of the reduction products changes accordingly. We propose to examine this process in more detail later.

EXPERIMENTAL

Preparation of mixture of Δ^3-menthene and Δ^2-menthene. Menthyl acetate, prepared from L-menthol and acetyl chloride, was decomposed thermally at 485-510° [6]. The yield of menthenes was 86%. The b.p. was 52 to 53° at 11.5 mm. The composition of the mixture (determined from the racemization of Δ^3-menthene by p--toluenesulfonic acid [10]), was 64.3% of Δ^3-menthene, and 35.7% of Δ^2-menthene.

Partial hydrogenation of mixture of menthenes. 124 g of the mixture of Δ^3- and Δ^2-menthenes, in 25 g portions, was partially hydrogenated in the presence of Raney Ni in alcohol solution. The hydrogenation was stopped when the volume of hydrogen absorbed reached a value corresponding to the Δ^2-menthene content of the mixture. We obtained 120 g of a mixture of Δ^3-menthene and menthane with α_D +54.4°. The Δ^3-menthene content of the mixture was about 60%.

Preparation of Δ^3-menthene oxide. To 58 g of the mixture of Δ^3-menthene and menthane, dissolved in 105 ml of chloroform, was gradually added 420 ml of a chloroform solution of perbenzoic acid (containing 38 g of C_6H_5COOOH). During the addition, the temperature of the reaction mixture was kept at from 2 to 9°, and the mixture was then left at room temperature. After 24 hours, the benzoic acid formed was extracted with 20% sodium hydroxide solution. After washing with water, drying with potassium carbonate, and removal of the chloroform, the reaction product was fractionated in vacuum. The main fraction had b.p. 74-74.5° at 14 mm, $n^{20}D$ 1.4436, d^{20}_4 0.8930, α_D +50.52°.

Reduction of Δ^3-menthene oxide under normal conditions. To a solution of 23 g of Δ^3-menthene oxide in ether was added 170 ml of an ether solution of lithium aluminum hydride (containing 8.3 g of LiAlH$_4$; 485% excess of reducing agent in comparison with the amount required theoretically). The reaction mixture was boiled for 3 hours. After careful addition of water to the reaction mixture and separation of the ether layer, the aqueous layer with a precipitate was treated with a concentrated solution of alkali, and then with ether. The combined ether extracts were washed with water and dried with potassium carbonate, and the ether removed by distillation. The reaction product (19.6 g) was distilled at 74-85° (7.5 mm) and had α_D +12.4°. The experiment was repeated twice. The combined reaction products, after distillation of the bulk of the unreduced oxide, were distilled on a column with an efficiency of 25 theoretical plates. The main fraction isolated had b.p. 82-83° (8.5 mm), $n^{20}D$ 1.4599, d^{20}_4 0.9046, α_D +0.36°.

Found %: C 76.74, 76.57; H 12.82, 13.00. Number of OH groups 1.02, 0.96. $C_{10}H_{20}O$.

Calculated %: C 76.85; H 12.90. Number of OH groups 1.00.

Phenylurethan of menthanol-4. A mixture of 1 g of the fraction with b.p. 82-83° (8.5 mm), 1 g of phenyl isocyanate, and 5 drops of pyridine was heated in a sealed tube on a water bath for 2 hours. After 12 hours, the tube was opened and 2 ml of benzene added to the reaction product. The precipitated crystals were collected, washed with water, and dried. After three recrystallizations from ligroine, the product had m.p. 95.5-96°.

Reduction of Δ^3-menthene oxide under drastic conditions. Over a period of 30 minutes, 170 ml of an ether solution of lithium aluminum hydride (containing 6 g of LiAlH$_4$; 390% excess of reducing agent) was added to 19.8 g of Δ^3-menthene oxide in 100 ml of ether. After the addition of the hydride, the ether was removed by distillation; the temperature of the reaction mixture was raised to 87°, and the residue changed into a white, gel-like mass. Then, after replacement of the distillation condenser by one for reflux, to the heated flask was gradually (dropwise at first) added 100 ml of ether with stirring, and, at this, the contents of the flask dissolved completely. After the usual processing, the reduction product (16.5 g) was distilled at 88-91° (11 mm); it had α_D +8.96°. In an experiment similar to the previous one, the ether was not distilled from the reaction mixture

completely; the temperature of the reaction mixture was raised to 60°. The original oxide was absent from the reaction products of both experiments. Distillation of the reduction products on a column yielded a main fraction with b.p. 84-85° (8 mm), $n^{20}D$ 1.4631, d^{20}_4 0.9084, α_D +9.40°.

Found %: C 76.66, 77.05; H 12.90, 13.00. Number of OH groups 0.99, 0.98. $C_{10}H_{20}O$.

Calculated %: C 76.85; H 12.90. Number of OH groups 1.00.

p-Nitrobenzoate of menthanol-3. To 0.9 g of the fraction with b.p. 84-85° (8 mm) was added 1.2 g of p--nitrobenzoyl chloride. The mixture was boiled for 3 minutes. The semiliquid mass formed was poured into water when it solidified. The reaction product was washed several times with sodium carbonate solution and water. After three recrystallizations from ligroine, the product had m.p. 55-55.5°.

Raman spectra. Spectrum of Δ^3-menthene oxide. $\Delta\nu$: 224(0), 290(1), 320(0), 364(1), 430(1), 501(0), 550 (0), 644 (1), 670 (1), 689 (3 broad), 760 (5), 792 (5), 813 (0), 851 (3 broad), 864 (3 broad), 910 (0), 952 (0), 1047 (4), 1101 (5 broad), 1128 (0), 1157 (5 broad), 1195 (5 broad), 1264 (0), 1278 (0), 1309 (2), 1351 (2 broad), 1429 (3), 1453-1464 (8 broad).

Spectrum of fraction with b.p. 82-83° (8.5 mm). $\Delta\nu$: 358 (0), 450 (3 broad), 612 (0), 679 (0), 708 (10), 789 (0), 762 (2 broad), 905 (0), 932 (1), 953 (1), 988 (1), 1024 (1), 1042 (2 broad), 1064 (0), 1084 (2), 1103 (0), 1132 (0), 1161 (8), 1266 (5), 1287 (1), 1303 (6), 1312 (1), 1340 (5), 1360 (0), 1392 (1), 1430 (3), 1456 (10).

Spectrum of fraction with b.p. 84-85° (8 mm). $\Delta\nu$: 364 (3 broad), 401 (0), 421 (0), 448 (3 broad), 492 (0), 518 (0), 588 (0), 613 (1), 639 (0), 659 (0), 680 (1), 709 (0), 760 (10), 771 (0), 813 (1), 839 (0), 860 (2), 905 (0), 932 (2), 955 (4), 990 (0), 1026 (2), 1066 (7), 1101 (6), 1155 (6 broad), 1190 (6 broad), 1215 (0), 1247 (3), 1268 (1), 1314 (5), 1344 (0), 1360 (5), 1392 (0), 1434 (3), 1456 (10).

SUMMARY

1. The reduction of Δ^3-menthene oxide with lithium aluminum hydride proceeds with greater difficulty than that of other, structurally similar terpene oxides.

2. Depending on the conditions, the main reduction product of Δ^3-menthene oxide was menthanol-4 (under normal conditions) or menthanol-3 (under drastic conditions).

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INVESTIGATION IN THE FIELD OF SYNTHESIS OF STEROID HORMONE ANALOGS
VII. SYNTHESIS OF TRANS-Δ^{4,9}-STERADIENONE-3

V. I. Maksimov and G. S. Grinenko

S. Ordzhonikidze All-Union Scientific Research Institute of Chemical Pharmaceutics

Original article submitted June 2, 1958

In the course of work on the synthesis of steroid hormone analogs, we prepared trans-Δ^{4,9}-steradienone-3 (VI) by the following scheme:
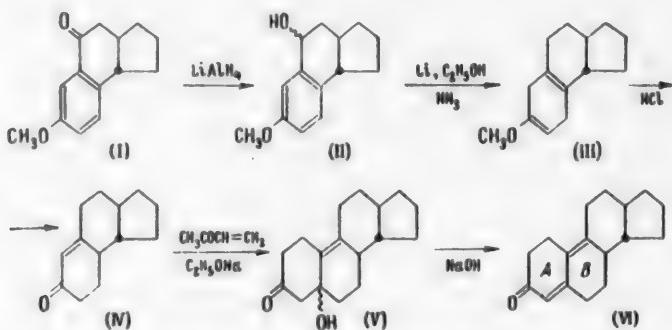
The synthesis of steradienone (VI) from trans-tricyclic ketone (I) [1] includes two main stages, namely, reduction of aromatic ring B and construction of ring A.

We reduced the aromatic ring by Wilds' method [2] with lithium in liquid ammonia and alcohol. Attempts to reduce the aromatic ring in the trans-ketone (I) with 50 equivalents of lithium were unsuccessful; the original ketone (I) was recovered. (Wilds used 30 equiv. of lithium for difficultly reducible compounds.) However, after reduction of the carbonyl group of ketone (I) to a hydroxyl group, saturation of the aromatic ring proceeded in quantitative yield with 50 equiv. of lithium. The UV spectrum of the reduction product, obtained with such an excess of lithium (Fig. 1, curve 3), indicated the presence of 1% of the original substance (II). With the use of 30 equiv. of lithium (curve 2), 21-22% of the original ether (II) remained unreduced. For comparison, the spectrum of substance (II) before reduction is presented in Fig. 1 (curve 1).

During the reduction, the hydroxyl group in a position α to the aromatic ring was eliminated. Hydrogenolysis of α-hydroxy groups is always observed in the reduction of an aromatic ring with metals dissolved in ammonia [3,4].

The enol ether (III) was hydrolyzed and isomerized by boiling with a dilute solution of hydrochloric acid in methyl alcohol. The unsaturated ketone (IV) obtained was purified by chromatography on aluminum oxide. The first, uncrystallizable eluate (eluted with ligroine) contained the unreduced phenol ether (II) (Fig. 2, curve 1). Subsequent elution with ligroine (curve 2) and a mixture of ligroine and benzene (curve 3), gave ketone (IV) with an absorption maximum at 239 mμ and lg ε 4.37. Such an absorption maximum in the ultraviolet spectrum is characteristic of a ketone in which the conjugated bond is secondary-tertiary (on the basis of Woodward's rule [5]).

Reduction of the carbonyl group in the trans-ketone (I) with lithium aluminum hydride gave a quantitative yield of only one of the two possible epimeric alcohols (II).
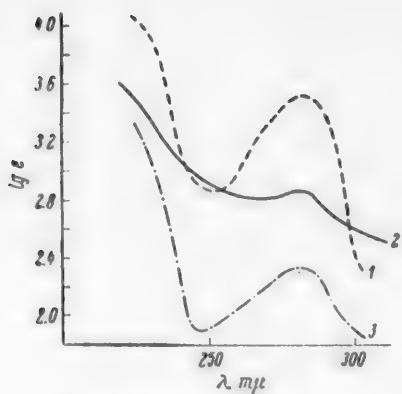
Fig. 1. Explanation in text.
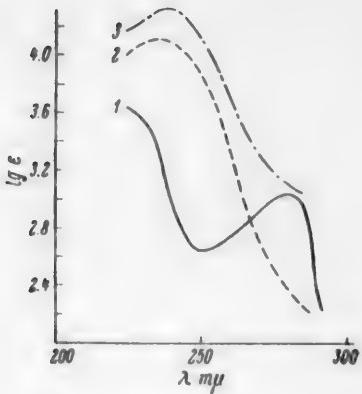
Fig. 2. Explanation in text.

Analogous conversions were carried out in the cis series. As with the trans-ketone (I), the aromatic ring in the cis-ketone (VII) was not reduced.
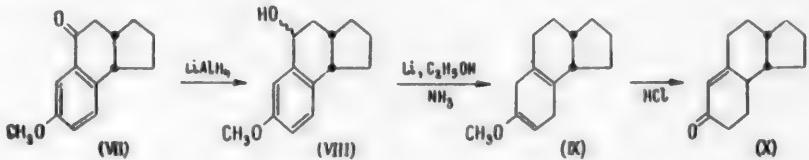
As a rule, compounds of the cis series had lower melting points than the corresponding compounds of the trans series (see Table 1).

We obtained trans-anti-trans-tricyclic ketone (XI) by reduction of the double bond in trans-ketone (IV) with lithium in liquid ammonia. The trans-anti-trans configuration was proposed for ketone (XI) because the reduction of α,β-unsaturated ketones with metals dissolved in ammonia proceeds stereospecifically with the formation of the stable configuration [6]. Such a configuration for the two coupled six-membered rings is anti-trans.
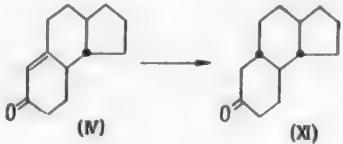
We constructed ring A under the conditions described by Miescher, Anner and Wieland [7]. We condensed the trans-ketone (IV) with methyl vinyl ketone in the presence of sodium ethylate in an alcohol–dioxane solution at low temperature. The keto alcohol (V) obtained was readily separated from the original ketone (IV), and methyl vinyl ketone by chromatography on aluminum oxide, since (V) contains a hydroxyl group and, therefore, is eluted from deactivated aluminum oxide by a mixture of ether and methanol (4:1), and ketone (IV) and methyl vinyl ketone are eluted by benzene. When the keto alcohol (V) was heated with a methanol solution of sodium hydroxide, dehydration occurred with the formation of the tetracyclic ketone (VI), which was isolated as an oily substance with an absorption maximum at λ 309 mμ, lg ϵ 4.47, characteristic of such a conjugated dienone. Trans-$\Delta^{4,9}$-steradienone-3 (VI) was characterized through its 2,4-dinitrophenylhydrazone with m.p. 253.5-254°.

EXPERIMENTAL

Trans-4-hydroxy-6-methoxy-1,2-cyclopentano-1,2,3,4-tetrahydronaphthalene (II). A solution of 2 g of trans-ketone (I) in 70 ml of dry ether was added dropwise to a suspension of 0.2 g of lithium aluminum hydride in 10 ml of dry ether, with vigorous stirring. After the addition, the mixture was boiled for 1 hour. The reaction

TABLE 1

Melting Points of Compounds of the Trans and Cis Series

Trans series	Ketone (I)	Semicarbazone of ketone (I)	Alcohol (II)	Acetate of alcohol (II)	Ketone (IV)	2,4-Dinitrophenyl-hydrazone of ketone (IV)
	95.5-96°	245°	92-93°	74-75°	54-55.5°	202-203.5°
Cis series	Ketone (II)	Semicarbazone of ketone (VII)	Alcohol (VIII)	Acetate of alcohol (VIII)	Ketone (IX)	2,4-Dinitrophenyl-hydrazone of ketone (IX)
	27-29°	169-170°	69-70°	83-84°	Liquid	173-175°

TABLE 2

Chromatography of Ketone (IV) on Aluminum Oxide

Fraction No.	Solvent	Residue after removal of solvent	
		weight (in g)	crystalline form
1	Ligroine with b.p. 30-60° (15 ml)	0.001	Did not crystallize
2	The same (50 ml)	1.2864	Needles
3	The same (50 ml)	0.1933	Needles
4	Mixture of ligroine with benzene (5:1; 50 ml)	0.1596	Needles
5	The same (1:1; 50 ml)	0.2522	Needles
6	Benzene (50 ml)	0.3880	Needles

mixture was then cooled with ice water and 2-3 ml of water added very slowly. Then a cooled 2% solution of hydrochloric acid was added slowly to the mixture until the precipitate of aluminum hydroxide dissolved completely. The ether layer was separated and the aqueous one extracted with ether. The ether extract was washed with water and dried. Removal of the ether gave a quantitative yield of (II) with m.p. 92-93° in the form of needles. Recrystallization from a mixture of benzene and ligroine did not change the melting point.

Found %: C 77.18; H 8.36. $C_{14}H_{18}O_2$.

Calculated %: C 77.02; H 8.30.

Trans-4-acetoxy-6-methoxy-1,2-cyclopentano-1,2,3,4-tetrahydronaphthalene. A mixture of 0.2 g of (II), 1 ml of dry pyridine, and 0.2 ml of acetic anhydride was kept at room temperature for 1.5 days. The reaction mass was poured into 20 ml of 5% hydrochloric acid, cooled with ice. The crystalline precipitate formed was collected by filtration and washed with water on the filter. Drying gave a quantitative yield of trans-4-acetoxy--6-methoxy-1,2-cyclopentano-1,2,3,4-tetrahydronaphthalene with m.p. 73-74° in the form of needles. After recrystallization from methyl alcohol, the product had m.p. 74-75°, λ_{max} 290 mμ, lg ε 3.46 (in ethanol).

Found %: C 73.95; H 7.84. $C_{16}H_{20}O_3$.

Calculated %: C 73.82; H 7.74.

Trans-6-methoxy-1,2-cyclopentano-1,2,3,4,5,8-hexahydronaphthalene (III). The reduction with lithium in liquid ammonia and alcohol was carried out in a three-necked flask, fitted with a stirrer, dropping funnel, and a tube with soda lime. The flask was placed in a wooden box with double walls. Into the two walls were let plexiglas windows so that the reaction could be observed in transmitted light. The box was filled with cotton wool for thermal insulation. Liquid ammonia from a tank was condensed in a spiral condenser, cooled with a mixture of solid carbon dioxide and ethylene glycol. The ammonia was collected directly in the reaction flask. To 300 ml of ammonia was added a solution of 2.85 g of (II) in 50 ml of dry ether. Then 3.84 g of lithium turnings was added over a period of 20 minutes with stirring. The lithium dissolved and the reaction mass acquired a blue

color. After a 10-minute interval, a sufficient amount of anhydrous alcohol was added to decolorize the reaction mixture (30 ml of alcohol over a period of 20-30 minutes). After evaporation of all the ammonia, a small amount of water was added, and the product extracted with ether. The ether extract was washed with saturated sodium chloride solution, and dried. Removal of the solvent yielded 2.67 g of (III) as a mobile oil.

Trans-1,2-cyclopentano-Δ^5-octalone-6 (IV). 2.67 g of (III), 120 ml of methyl alcohol, and 6 ml of conc. HCL were boiled for 15 minutes. The residue after removal of the methyl alcohol in vacuum was extracted with ether. The ether extract was washed with water until neutral, and dried. Removal of the ether yielded 2.3 g (94% yield) of a colored oil. The substance was dissolved in ligroine and passed through a column with 30 g of aluminum oxide (Table 2).

We obtained 2.25 g of trans-1,2-cyclopentano-Δ^5-octalone-6 (IV) with m.p. 54-55.5°, λ_{max} 239 mμ, lg ϵ 4.37 (in ethanol). The yield was 97.5%.

Found %: C 81.86; H 9.34. $C_{13}H_{18}O$.

Calculated %: C 82.00; H 9.53.

2,4-Dinitrophenylhydrazone of trans-1,2-cyclopentano-Δ^5-octalone-6. To a solution of 0.07 g of 2,4-dinitrophenylhydrazine in 7 ml of anhydrous alcohol and 0.35 ml of conc. HCl, was added a solution of 0.056 g of 1,2-cyclopentano-Δ^5-octalone-6 (IV) in 1 ml of anhydrous alcohol. The orange precipitate formed was collected and washed on the filter with alcohol and ethyl acetate. The m.p. was 202-203.5°.

Found %: N 14.97. $C_{19}H_{22}O_4N_4$.

Calculated %: N 15.13.

Attempted reduction of trans-4-keto-6-methoxy-1,2-cyclopentano-1,2,3,4-tetrahydronaphthalene (I) with lithium in liquid ammonia and alcohol. To a solution of 2.45 g of trans-ketone (I) in 100 ml of ether, and 300 ml of ammonia was added 3.7 g of lithium turnings over a period of 20 minutes. The reduction was carried out under the conditions described above.[*] The processing described yielded 2.3 g of a substance with m.p. 94.5-95.5° (after recrystallization from alcohol). A mixed melting point with the original ketone (I) was not depressed.

Trans-anti-trans-1,2-cyclopentanodecalone-6 (XI). To 500 ml of liquid ammonia was added a solution of 1.25 g of (IV) in 12 ml of dry ether and 12 ml of pure, dry dioxane. Then 0.12 g of fine lithium turnings was added over a period of 20 minutes with stirring. The reaction mixture acquired a blue color. After 45 minutes' stirring, the ammonia was removed under reduced pressure. Between the reaction flask and the water pump was placed a drying bottle with alkali. After evaporation of the ammonia, the blue color disappeared. The reaction mass was left for 16 hours at room temperature, and then it was carefully decomposed with water and the reaction product extracted with ether. The ether extract was washed with water and dried with sodium sulfate. The residue after removal of the ether (1.1 g) was a mobile oil, which was chromatographed on 30 g of aluminum oxide. The first four fractions of benzene (25 ml each) contained 0.76 g (60.2%) of trans-anti-trans-1,2-cyclopentanodecallone-6 (XI) with m.p. 32-34°. The following fractions did not give a Zimmerman reaction.

Found %: C 80.96; H 10.43. $C_{13}H_{20}O$.

Calculated %: C 81.25; H 10.48.

2,4-Dinitrophenylhydrazone of trans-anti-trans-12-cyclopentano-decalone-6 had m.p. 133-134° after recrystallization from a mixture of alcohol and ethyl acetate (4:1).

Found %: C 60.94; H 6.61; N 14.09. $C_{19}H_{24}O_4N_4$.

Calculated %: C 61.27; H 6.49; N 15.04.

Cis-4-hydroxy-6-methoxy-1,2-cyclopentano-1,2,3,4-tetrahydronaphthalene (VIII). 2.2 g of cis-4-keto-6-methoxy-1,2-cyclopentano-1,2,3,4-tetrahydronaphthalene (VII) in 70 ml of dry ether was reduced with 0.23 g of lithium aluminum hydride, as described above. The processing was analogous to that described. We obtained a quantitative yield of (VIII) with m.p. 69-70° as needles. After recrystallization from a mixture of ether and ligroine, the product had m.p. 72-73°.

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[*] The lithium complex was decomposed with 55 ml of alcohol.

Found %: C 76.92; H 8.23. $C_{14}H_{18}O_2$.

Calculated %: C 77.02; H 8.30.

Cis-4-acetoxy-6-methoxy-1,2-cyclopentano-1,2,3,4-tetrahydronaphthalene. A mixture of 0.5 g of (VIII), 2 ml of pyridine, and 0.4 ml of acetic anhydride was left at room temperature for 35 hours. The reaction mixture was then poured into water. The crystalline precipitate was collected by filtration and washed with water. We obtained a quantitative yield of cis-4-acetoxy-6-methoxy-1,2-cyclopentano-1,2,3,4-tetrahydronaphthalene with m.p. 83-84°. Recrystallization from methyl alcohol did not change the melting point.

Found %: C 73.98; H 7.84. $C_{16}H_{20}O_3$.

Calculated %: C 73.82; H 7.74.

Cis-1,2-cyclopentano-Δ^5-octalone-6 (X). a) 11 g of (VIII) was reduced with 15 g of lithium (as turnings) in a mixture of 700 ml of liquid ammonia and 250 ml of dry ether under the conditions described above. The lithium complex was decomposed with anhydrous alcohol (160 ml). Appropriate processing yielded 10 g of cis-6--methoxy-1,2-cyclopentano-1,2,3,4,5,8-hexahydronaphthalene as a mobile oil. The yield was 97%. According to ultraviolet spectral data, the substance did not contain the original (VIII).

b) The hydrolysis and isomerization of 10 g of (IX) was carried out in 450 ml of methyl alcohol with 12.5 ml of conc. HCl under the conditions of the experiment described above. Appropriate processing gave 9.83 g (quantitative yield) of cis-1,2-cyclopentano-Δ^5-octalone-6 as a colorless, mobile liquid with b.p. 107-111° at 0.55 mm, $n^{20}D$ 1.537, λ_{max} 244 mμ, lg ϵ 4.38 (in ethanol).

Found %: C 82.05; H 9.45. $C_{13}H_{18}O$.

Calculated %: C 82.00; H 9.53.

2,4-Dinitrophenylhydrazone of cis-1,2-cyclopentano-Δ^5-octalone-6 had m.p. 173-175° after recrystallization from alcohol.

Found %: C 61.57; H 5.96; N 14.65. $C_{19}H_{22}O_4N_4$.

Calculated %: C 61.60; H 5.97; N 15.13.

Trans-$\Delta^{4,9}$-steradienone-3 (VI). a) To a solution of sodium ethylate (prepared from 0.17 g of sodium and 55 ml of anhydrous alcohol), was added a solution of 1.4 g of (IV) in 22 ml of dry dioxane (free from peroxides) in a stream of nitrogen at room temperature. The reaction mass was cooled to −10° and a solution of 1.5 ml of methyl vinyl ketone in 4 ml of dioxane was added dropwise over a period of $\frac{1}{4}$ hour. After the addition, the reaction mixture was stirred for 15 hours at a temperature of from −10 to −5°. Acetic acid (2 ml) was then added to a weakly acid reaction, and the solvent was removed in vacuum. The residue was dissolved in a small amount of water and extracted with benzene. The benzene extract was washed with sodium bicarbonate solution and water, and dried with sodium sulfate. Removal of the benzene gave 2.2 g of substance in the form of a light oil, which, on addition of ether, yielded a crystalline side product (0.25 g) with m.p. 212-214° (we did not examine this). The mother solution was evaporated and the residue, dissolved in a mixture of benzene and ligroine (3:1) was chromatographed on a short column with aluminum oxide, deactivated with ethyl acetate. Elution with benzene and ether yielded 1.35 g of a mixture of starting ketone (IV) and a polymer of methyl vinyl ketone. Elution with a mixture of ether and methanol (4:1) gave the main product, Δ^9-steradienol-5-one-3, (0.57 g) as a partly crystalline substance, which was used in the following stage without purification.

b) A solution of 0.57 g of substance (V) in 57 ml of methanol was boiled in a stream of nitrogen with 7 ml of 2 N sodium hydroxide for $1\frac{1}{4}$ hours. After being made weakly acid with acetic acid (to litmus), the reaction mixture was evaporated in vacuum. The residue was diluted with water and extracted with ether. The ether extract was washed with sodium bicarbonate solution and then water, and dried. Removal of the solvent yielded 0.48 g of a dark red oil, which boiled at a bath temperature of 200-210° (at 0.02 mm). The ultraviolet spectrum of the substance contained a maximum characteristic of dienones with conjugation of the double bonds [λ_{max} 309 mμ, lg ϵ 4.47 (in ethanol)].

The 2,4-dinitrophenylhydrazone of trans-$\Delta^{4,9}$-steradienone-3 had m.p. 253.5-254° after recrystallization from alcohol.

Found %: C 64.94; H 6.22; N 13.16. $C_{23}H_{26}O_4N_4$.

Calculated %: C 65.38; H 6.26; N 13.26.

SUMMARY

1. Trans-$\Delta^{4,9}$-steradienone-3 was synthesized.

2. It was shown that reduction of the aromatic ring in cis- and trans-4-hydroxy-6-methoxy-1,2-cyclopent-ano-1,2,3,4-tetrahydronaphthalene with lithium in liquid ammonia and alcohol was accompanied by hydrogenolysis of the α-hydroxyl and gave a yield close to quantitative.

3. Cis- and trans-4-keto-6-methoxy-1,2-cyclopentano-1,2,3,4-tetrahydronaphthalenes were not reduced by lithium in liquid ammonia and alcohol, even when 50 equivalents of lithium were used.

4. Reduction of the carbonyl group in both the cis- and trans-ketones [(I) and (VII)] proceeded stereospecifically with the formation of only one epimeric alcohol.

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INVESTIGATION OF THE NATURE OF CATALYSTS USED
FOR THE ISOMERIZATION AND POLYMERIZATION OF HYDROCARBONS
II. THE CATALYTIC PROPERTIES OF SILICIC ACID*

G. A. Rudakov and M. M. Shestaeva

Central Scientific Research Institute of Wood Chemistry

Original article submitted May 29, 1958

Aluminosilicates, titanic acid, and other solid catalysts used for the catalytic isomerization and polymerization of hydrocarbons have strongly expressed acidic properties. According to modern ideas, this determines the catalytic activity of the catalysts indicated [1,2]. On the other hand, the acidic properties of silicic acid are very weak. Therefore, one would not expect silica gel to have any catalytic activity; in any case, at low and at moderate temperatures.

Information available in the literature on the catalytic activity of silica gel is contradictory and frequently does not support the ideas presented.

Thus, B. A. Arbuzov and Z. G. Isaeva [6] observed the isomerization of α-pinene, Δ^3-carene, and limonene on silica gel under the conditions of chromatographic analysis at $+10°$. The isomerization of pinene was complete and, in composition, the reaction products were similar to those obtained by the isomerization of pinene in the presence of aluminosilicate catalysts. Δ^3-Carene and limonene were isomerized somewhat more slowly than α-pinene. Also, under the conditions of chromatographic analysis on silica gel, Gallaway and Murray [7] observed the isomerization of 2,4,4-trimethylpentenes, 2-ethyl-hexene-1, and of other alkenes of the structure $RR'C=CH_2$ at $+25°$.

On the other hand, a series of authors have reported the very weak catalytic activity of silica gel, and even its complete absence. Thus, Thomas [5] did not find any activity for silica gel, obtained by hydrolysis of ethyl orthosilicate, in the cracking of Pennsylvania gasoline. B. N. Rutovskii and V. I. Lyubomilov [8] reported the insignificantly small catalytic activity of reactive silicic acid. After 9 hours' boiling with 3% of this catalyst, α-pinene was only 15-18% isomerized. V. E. Tishchenko and G. A. Rudakov [2] did not detect the isomerization of α-pinene in the presence of silica gel, obtained by A. P. Okatov's method [9], at room temperature, but G. A. Rudakov achieved complete isomerization of pinene with the same catalyst at $155°$ [10,11].

It is known that, when aluminum oxide is introduced into silicic acid gel (by coprecipitation or by impregnation of silica gel with an aluminum salt and subsequent firing), the catalytic properties of the gel are sharply increased [5,12,13]. The explanation of this may be found in the work of V. I. Vernadskii and L. Pauling [3,14,15]. According to some data, even the introduction of 0.1% of aluminum oxide into a silicic acid gel is sufficient to give an active catalyst [13].

At the same time, one cannot exclude the possibility of small amounts of Al_2O_3 being present in silica gels prepared technically, since, as a rule, the sodium silicate used for the preparation of silica gels contains aluminum [16]. For improving the stability, from 4 to 10% of aluminum oxide is introduced artificially into certain sorts of silica gel produced by our industry [17].

If we consider that, in almost all the work devoted to catalysis by silica gels, there is no data on the chemical and physicochemical characteristics of the original catalysts, then there are grounds for proposing that the

*For report I see [1].

Properties of Catalysts Studied

Catalyst No.	Characteristic of catalyst	Ignition loss, (in %)	Al_2O_3 content (in %)	Surface (in m^2 per g)	Pore volume (in ml per 100 g)	pH of aqueous suspension	Amt. of CH_3COONa (in mg-equiv) reacting with 1 g catalyst	Camphene content of isomerizate (in %) in complete isomerization of pinene
1	Silica gel, industrial product, KSK grade, granulated [17]	5.57	0.75	194	—	7.61	0.04	—
2	The same, ShSK grade [17]	5.63	1.00	192	—	7.44	0.04	45
3	The same, ShSM grade, lumps [17]	4.75	1.36	98	—	3.42	0.21	—
2-0	Silica gel, obtained from catalyst No.2 by treatment with HCl	2.62	0.73	123	89	3.80	0.085	45
5	Silica gel obtained from $SiCl_4$	2.46	None	150	83.5	5.56	0.11	—
5-3	The same, impregnated with $Al(NO_3)_3$ and fired	—	0.11	—	—	3.80	0.16	42
5-2	The same	2.52	0.53	155	85	3.97	0.184	—
5-1	The same	—	5.3	—	—	4.66	0.332	50
5-4	The same	—	17	152	62.5	5.50	0.410	45
5-6	The same	—	32	105	46	6.00	0.265	50
6	Aluminum oxide	3.40	99.6	—	—	7.25	0	—
7	Activated Chasov Yar clay	—	—	88	—	3.49	0.138	57

Chemical Composition (in percents) of Industrial Silica Gels Used (Voskresensk Chemical Combine)*

Oxides	Catalyst number			
	1	2	3	2-0
SiO_2	97.64	96.84	98.20	97.68
Al_2O_3	0.79	1.05	1.42	0.75
Fe_2O_3	0.23	0.24	0.24	0.10
CaO	0.60	0.97	(Not determined)	0.84
MgO	0.31	0.52	—	0.51
Na_2O	(Not determined)	0.21	—	(Not determined)
Total	99.57	99.83	99.86	99.88

* The analyses were calculated on absolutely dry material.

cases of catalytic isomerization of unsaturated hydrocarbons by silica gels described, especially at low temperature [6,7], were caused by their aluminosilicate content. In only one of the works cited was silica gel used, whose preparation conditions excluded the presence of aluminum [5], and in precisely this work silica gel was found to have no catalytic activity.

An unequivocal solution to the problem of the catalytic properties of silicic acid gels is important for understanding the mechanism of heterogeneous acid catalysis, and is no less important for solving the problem of the legitimacy of using silica gel as a sorbent in the chromatography of unsaturated hydrocarbons. In this connection, the present investigation was undertaken to analyze the available contradictory data on the catalytic properties of
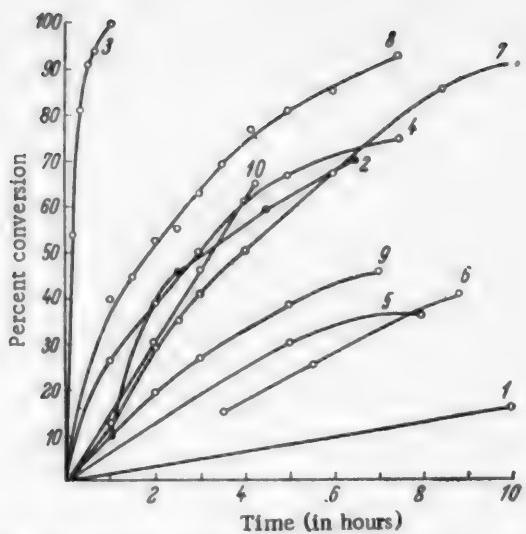
Rate of catalytic isomerization of α-pinene: 1) catalyst No. 5, 10%, 155°; 2) catalyst No. 2, 2%, 1 hour after the beginning of the reaction 4%, 155°; 3) catalyst No. 2-0, 2%, 155°; 4) catalyst No. 2-0, 4%, 100°; 5) catalyst No. 2-0, 20%, 20°; 6) catalyst No. 3, 40%, 20°; 7) catalyst No. 5-3, 2%, 1 hour after the beginning of the reaction 3%, after 4.5 hours 4%, 100°; 8) catalyst No. 5-1, 1%, 100°; 9) catalyst No. 5-6, 1%, 100°; 10) catalyst No. 7, 1%, 100°.

silica gels. Studies were made of the properties of a series of laboratory and factory silica gels, free from traces of Al_2O_3, and containing it, and an evaluation made of the catalytic properties of the most characteristic samples. The properties of these gels were compared with those of alumino-silicates and aluminum oxide. The characteristics of the gels studied, and the activated Chasov Yar clay and aluminum oxide used for comparison with them, are given in Tables 1 and 2.

The data in the tables show that silica gel obtained by hydrolysis of $SiCl_4$ and consequently free from Al_2O_3, gave an aqueous suspension with a pH value close to neutral, and had an insignificantly small exchange capacity with CH_3COONa (catalyst No. 5). After deposition of 0.1 to 0.5% of Al_2O_3 onto the surface of this silica gel, the pH of its acid suspension passed into the acid region, and the exchange capacity increased without a change in the specific surface or the porosity (catalyst Nos. 5-3 and 5-2). With the introduction of larger amounts of Al_2O_3, the pH value of an aqueous suspension of the catalyst began to increase, and the pore volume decreased (probably due to blocking with Al_2O_3), but the exchange capacity continued to increase (catalyst No. 5-4). With the introduction of a very large amount of Al_2O_3, the pH value of an aqueous suspension of the gel became very close to neutral, and the value of the

specific surface, the pore volume, and the exchange capacity decreased (catalyst No. 5-6). The latter was probably caused by blocking of the whole catalyst surface by aluminum oxide, which does not exchange with CH_3COONa (catalyst No. 6).

The table also shows that industrial silica gel contains considerable amounts of Al_2O_3. Coarsely porous silica gels (catalysts Nos. 1 and 2), which did not differ in specific surface and pore volume from silica gels obtained from $SiCl_4$, differed in the pH values of aqueous suspensions (these values lay in the alkaline region). The capacity for exchange with CH_3COONa of such gels was low. This was probably the result of sorption of cations during washing of the silica gel with insufficiently pure water during production. The impurities were removed from catalyst No. 2 by treatment with hydrochloric acid and subsequent washing with water (catalyst No. 2-0). In its chemical properties, the finely porous silica gel (catalyst No. 3) was similar to silica gels obtained from $SiCl_4$ and containing Al_2O_3, but differed from them in specific surface, and had a lower pore volume.

The catalytic properties of the most characteristic samples of the substances presented in Table 1 were evaluated from their capacity to catalyze the isomerization of α-pinene. Pinene was chosen since its isomerization involves very readily proceeding and conveniently controllable processes. The results obtained are presented graphically (see figure).

The data presented show that the gel obtained by hydrolysis of $SiCl_4$ and not containing aluminum (catalyst No. 5) had an extremely low catalytic activity at 155°. Its catalytic activity was so low that it was impossible to be sure that it did not arise from very small amounts of impurities. At 100°, this gel had no catalytic activity.

All the other gels, containing aluminum, were much more effective catalysts of pinene isomerization. In comparing the catalytic activities of these gels with each other and with the activity of catalyst No. 5, it was considered that the reaction rate at 155° was 40 times greater than the reaction rate at 100° (curves 3 and 4), and, also, that the reaction rate was proportional to the amount of catalyst introduced. Comparison of the data obtained shows that at 155° the industrial sample of coarsely porous silioa gel with the surface poisoned with sorbed cations

(catalyst No. 2) produced an isomerization of pinene that was 25 times faster than that produced by catalyst No. 5, but at +20° this gel was catalytically inactive. At 155°, the same gel, after removal of the sorbed cations, produced a reaction 1000 times faster than silica gel No. 5, and maintained its catalytic activity at 100 and 20° (catalyst No. 2-0). The industrial sample of finely porous silica gel (catalyst No. 3) also catalyzed the reaction at +20°. Precipitation of 0.1% of Al_2O_3 on the surface of catalyst No. 5 increased the isomerization rate by a factor of 1300, precipitation of 5% Al_2O_3, by a factor of 5200, and of 30% Al_2O_3 by a factor of 2000. Comparison of the catalytic activity of various silica gels containing aluminum with the catalytic activity of activated clay showed that their activities were of approximately the same order.

It was established that aluminum oxide, obtained by firing aluminum nitrate (catalyst No. 6) lacked catalytic activity at 155°. This shows that the activity of silica gels containing aluminum was due to the formation of aluminosilicate on the silica gel surface, and not the precipitation of active aluminum oxide.

The products of the catalytic isomerization of α-pinene on silica gel were similar in composition to products obtained in the presence of active clays. They also contained camphene and monocyclic terpenes, but there was slightly less camphene in them.

EXPERIMENTAL

Before use, the silica gels prepared industrially (Voskresensk Chemical Combine) were powdered and dried at 110°, or fired at 350°. Silica gel No. 3 contained traces of free acid, and it was therefore washed first.

For the preparation of catalyst No. 2-0, 90 g of powdered catalyst No. 2 was kept under a layer of hydrochloric acid (d 1.12) for two days, and then the hydrochloric acid was poured off and the silica gel washed by decantation. Titration of 100 ml of wash water from the latter required 0.1 ml of 0.1 N NaOH solution.

Catalyst No. 5 was obtained by A. V. Kiselev's method [18], from $SiCl_4$ (reagent), distilled in a stream of dry air. The washing was similar to the washing of catalyst No. 2-0. Before use, the silica gel was powdered and fired at 350-400°.

Catalysts Nos. 5-1, 5-2, and 5-3 were prepared by impregnating powdered catalyst No. 5 with a given amount of aluminum nitrate solution, drying, and firing at 350-400°. Catalysts Nos. 5-4 and 5-6 were treated with aluminum nitrate solution three times. After each treatment, they were dried at 200° and, after the last treatment, they were also fired at 350-400°.

For the preparation of catalyst No. 6, aqueous aluminum nitrate was dried in a porcelain dish on a water bath for 12 hours. The paste formed was dried at 120°, and then fired at 350-400° for 3 hours.

Activated clay was prepared by treating Chasov Yar clay No. 5 with hydrochloric acid under the conditions described previously [2].

The specific surface of the silica gel was determined from the adsorption of Methylene blue [1]. As is known, in determining the absolute value of specific surfaces by this method, considerable errors are possible due to the fact that the large dye molecules have difficulty in penetrating the fine pores of the material investigated. These errors probably had effect in determining the surface of catalyst No. 3. However, since it was most interesting to determine not the absolute value of the specific surfaces of the catalysts, but the so-called effective specific surfaces [19], accessible to the comparatively large pinene molecules, the method used was suitable.

The total pore volume of the catalysts was determined by the exsiccator method from the weight of water absorbed [20].

The pH value of aqueous suspensions of the catalysts was measured with a glass electrode. For preparing the suspension, 5 g of catalyst was shaken with 25 ml of water. The suspension was stored for 12 hours before the determination.

The exchange capacity of the catalysts with CH_3COONa was determined by Yu. A. Bitepazh's method [4].

The pinene used for the investigation was obtained from an industrial rectification apparatus. The pinene had the following properties: $n^{20}D$ 1.4665, d^{20}_4 0.8592, α_D +21.78°, and consisted of 94% α-pinene and 6% β-pinene.

The isomerization was carried out in a three-necked flask with continuous stirring. As an inhibitor, 0.01% of hydroquinone was added. During the course of the process, samples were withdrawn and the camphene content determined analytically [21] and from the data obtained, the percentage isomerization of the pinene was found [22]. If the physical constants of the pinene remained unchanged after 4-6 hours, despite the introduction of a new portion of catalyst, we came to the conclusion that the catalyst was inactive under the test conditions. This was the conclusion in testing catalyst No. 5 (10%) at 100°, and catalyst No. 2 (40%) at +20°.

SUMMARY

1. Silica gel free from aluminum did not catalyze the isomerization of α-pinene at 100°, but catalyzed it at a very low rate at 155°. When 0.1% of aluminum oxide was precipitated on the surface of such a gel, its catalytic activity at 155° was increased by a factor of 1300 and became of the same order as that of activated clay. Silica gel, produced by our industry, contained about 1% of aluminum oxide (and special grades, up to 10%) and, therefore, catalyzed the isomerization of α-pinene even at +20°.

2. What has been stated explains the ready isomerization of α-pinene and other unsaturated hydrocarbons under the action of silica gel observed by certain authors, and also confirmed the theory of aluminosilicate catalysis formulated by V. E. Tishchenko and G. A. Rudakov [2], since the ready isomerization of unsaturated hydrocarbons under the action of such a weak acid as silicic contradicts this theory.

3. The results of the work showed that silica gel, free from aluminum, may be used for the chromatographic separation of unsaturated hydrocarbons. The use of technical gels containing about 1% of aluminum oxide for this purpose is only permissible if the aluminosilicic acids in them are neutralized. The problem of how such neutralization affects the separating properties of the gels remains open, as yet.

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SOME BENZTHIAZOLE DERIVATIVES

VI. A NEW METHOD OF SYNTHESIZING 2-HYDRAZINOBENZTHIAZOLEMONO-
AND DICARBOXYLIC ACIDS

I. A. Solov'eva and A. G. Guseva

All-Union Motion Picture Scientific Research Institute

Original article submitted April 4, 1958

Hydrazines of the heterocyclic series are usually synthesized by reaction of the appropriate halo, hydroxy, or sulfono derivatives with hydrazine. Thus, 2- and 4-hydrazino derivatives of quinoline [1] and pyridine [2], and also certain 2-hydrazinobenzthiazoles [3] are readily obtained by the action of hydrazine hydrate on the chloro derivatives. A convenient method of preparing 2-hydrazino derivatives of benzthiazole, benzoxazole, and benzimidazole is the facile reaction between the appropriate 2-sulfonic acids and hydrazine hydrate [4-8]. The reduction of appropriate diazo derivatives has been used comparatively rarely [9-11].

However, the methods of preparing heterocyclic hydrazines enumerated above are not very convenient for the preparation of certain derivatives of benzthiazole, in particular, those of its mono- and dicarboxylic acids.

It is known that, by heating the amides of aromatic carboxylic acids with hydrazine hydrate, the amino group may be replaced by a hydrazino group [12]. An analogous reaction occurs in the interaction of certain imido esters with phenylhydrazine [13].

One might also surmise that 2-aminobenzthiazole, in which the nitrogen atom of the amino group evidently has an amide character, would also react with hydrazine hydrate. In this connection, we investigated the action of hydrazine hydrate on 2-aminobenzthiazole and its derivatives.

It was found that when 2-aminobenzthiazole was heated with an aqueous solution of hydrazine hydrate at 120°, vigorous evolution of ammonia occurred. The product which precipitated on cooling readily formed a silver mirror with an ammoniacal solution of silver nitrate, and condensed with acetoacetic ester with the formation of 1-(benzthiazolyl-2')-3-methylpyrazolone [7].

On the basis of this, and also analysis data, it may be accepted that elimination of the amino group occurred in this reaction, and that benzthiazolyl-2-hydrazine (I) was formed.

On weak acidification of the solution after separation of the benzthiazolyl-2-hydrazine, a yellow oil was liberated, and this readily dissolved in hydrochloric acid and in sodium hydroxide solution. In air it was rapidly converted into a crystalline product with m.p. 90-91°. The substance formed was 2,2'-diaminodiphenyl disulfide (II), as was demonstrated by a mixed melting point. Thus, in the action of hydrazine hydrate on 2-aminobenzthiazole, there was partial rupture of the benzthiazole ring with the formation of o-aminothiophenol (cf. [14]).
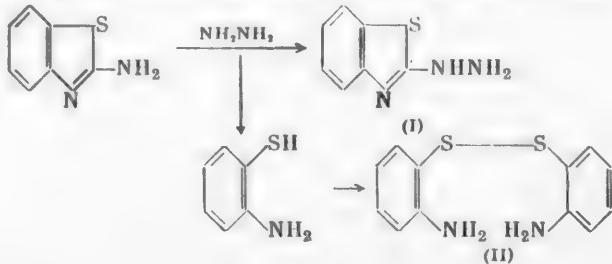
The yield of 2-hydrazinobenzthiazole decreased sharply when the time of heating 2-aminobenzthiazole with hydrazine hydrate was increased. At the same time, the yield of 2,2'-diaminodiphenyl disulfide increased correspondingly (from 43% to 71%). Apparently, when 2-hydrazinobenzthiazole was heated with hydrazine hydrate, rupture of the benzthiazole ring also occurred.

In an attempt to achieve the same reaction with substituted 2-aminobenzthiazoles, it was found that 6-ethoxy- and 5,6-dimethyl-2-aminobenzthiazoles did not react with hydrazine hydrate under analogous conditions; after many hours heating, they could be recovered unchanged. This phenomenon was apparently connected both with effect of the substituents in the benzthiazole nucleus on the character of the amino group and the low solubility of these compounds in the reaction mixture.

As was found, 2-aminobenzthiazolecarboxylic acids [15] behaved completely differently under analogous conditions. Thus, when 2-aminobenzthiazole-6-carboxylic acid was heated with an aqueous solution of hydrazine hydrate at 120-130°, intense evolution of ammonia was observed, which ceased after 6-9 hours. The substance which precipitated on acidification gave a characteristic reaction for a hydrazino group (silver mirror) and reacted with stearoylacetic ester to form the corresponding pyrazolone derivative [16]. These properties and analysis data make it possible to ascribe the structure of 2-hydrazinobenzthiazole-6-carboxylic acid (III) to the compound obtained. The yield was 85%.

Similarly, from 2-aminobenzthiazole-5,6-, 5,7-, and 6,7-dicarboxylic acids [17], we obtained good yields of the corresponding 2-hydrazino derivatives (IV-VI).

R_1, R_2 = H, R_3 = COOH (III);
R_1, R_2 = COOH, R_3 = H (IV);
R_1, R_3 = COOH, R_2 = H (V);
R_2, R_3 = COOH, R_1 = H (VI).
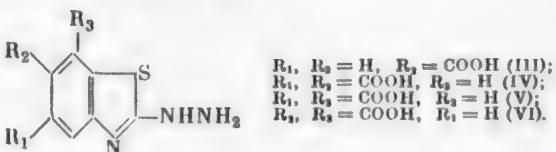
The method described above is extremely convenient for synthesizing 2-hydrazinobenzthiazolemono- and dicarboxylic acids, which are thus obtained in a very pure state.

The 2-aminobenzthiazole-5,7-dicarboxylic acid mentioned above was obtained by hydrolysis of the corresponding dimethyl ester, which was synthesized by oxidizing 3,5-dicarbomethoxyphenylthiourea with bromine (cf. [18, 19]).

The authors would like to thank I. I. Levkoev for valuable advice given during this work.

EXPERIMENTAL

Reaction of 2-aminobenzthiazole with hydrazine hydrate. A mixture of 7.5 g of 2-aminobenzthiazole and 60 ml of 33% hydrazine hydrate solution was heated on an oil bath (at 120-125° in the oil) for 10 hours, when vigorous evolution of ammonia was observed. The precipitate which formed on cooling was collected, washed with water, and dried. The weight was 3.0 g, and the m.p. 180-182°. The substance was purified by two recrystallizations from ethyl alcohol. The m.p. was 199-200° (205° [1]; 194-195° [7]). The product formed a silver mirror with an ammoniacal solution of silver nitrate.

Found %: N 25.54. $C_7H_7N_3S$.

Calculated %: N 25.46.

The filtrate was made weakly acid with hydrochloric acid. The precipitated oil was extracted with ether, the ether removed, and the residue mixed with 20 ml of 15% sodium acetate solution. A yellow precipitate formed rapidly, and after several hours, this was collected, washed with water, and dried. The weight was 2.7 g (43.5%). The m.p. was 90-91° (from alcohol). A mixed melting point with o,o'-diaminodiphenyl disulfide was not depressed.

3,5-Dicarbomethoxyphenylthiourea. 20.9 g of dimethyl 5-aminoisophthalate was dissolved with heating in 60 ml of dilute (1:5) hydrochloric acid, and to the dark solution was added 11.7 g of potassium thiocyanate. The reaction mixture was heated for 14 hours in an open flask on an oil bath (at 102-110° in the oil) and the solid residue was ground and heated for a further 10 hours at 110-115°. The product was then stirred with 100 ml of

Name of compound	Amount (in moles)		Bath temperature	Heating time (in hrs)	Amount of hydrochloric acid in processing	Yield (in %)	Found		Formula	Calculated	
	amine	hydrazine hydrate					N(%)	equiv.		N(%)	equiv.
2-Hydrazinobenzthiazole-6-carboxylic acid*	0.1	0.3 (25% solution)	120–125°	9	300 ml 15%	85	20.11	210.0	$C_8H_7O_2N_3S$	20.09	209.1
2-Hydrazinobenzthiazole-5,7-dicarboxylic acid	0.1	1.0 (50% solution)	130–135	7–8	150 ml 36%	69.2	16.59	126.0	$C_9H_7O_4N_3S$	16.60	126.7
2-Hydrazinobenthiazole-5,6-dicarboxylic acid	0.01	0.03 (25% solution)	120–125	6	50 ml 36%	83.0	16.30	125.8	$C_9H_7O_4N_3S$	16.60	126.7
2-Hydrazinobenzthiazole-6,7-dicarboxylic acid	0.01	0.03 (25% solution)	120–125	7	50 ml 36%	90.4	16.32	127.1	$C_9H_7O_4N_3S$	16.60	126.7

* The product, isolated after reprecipitation from sodium carbonate solution, was treated with 30 ml of 10% sodium acetate solution, washed with water, and dried.

water and the precipitate collected, ground with 70 ml of dilute (1:2) hydrochloric acid, washed with water, dried, and recrystallized from alcohol. The yield was 13.4 g (50%). The m.p. was 178-179°. For analysis, the substance was recrystallized three times from alcohol. The colorless prisms had m.p. 182-183°. The product was quite readily soluble in alcohol, ether, and benzene, more difficultly so in chloroform, and insoluble in water.

Found %: N 10.45. $C_{11}H_{12}O_4N_2S$.

Calculated %: N 10.44.

Dimethyl ester of 2-aminobenzthiazole-5,7--dicarboxylic acid. Over a period of 30 minutes, 28 g of sulfuryl chloride and a solution of 16 g of bromine in 30 ml of chlorobenzene were added with stirring to a suspension of 53.6 g of 3,5-dicarbomethoxyphenylthiourea in 270 ml dry chlorobenzene. The reaction mixture was stirred for 10 hours at 60-65°, and the precipitate collected, washed with benzene, dried, and introduced into 1 liter of boiling water. To the hot solution was added 10% sodium carbonate solution to an alkaline reaction, and the precipitate was collected, washed with water, dried (weight 40.2 g), and recrystallized from 270 ml of glacial acetic acid. The yield was 22.4 g (42.2%). The product formed colorless crystals. It was soluble in acetone, in acetic acid, and alcohol on heating, and difficultly soluble in ether and benzene. The m.p. was above 300°.

Found %: N 10.54. $C_{11}H_{10}O_4N_2S$.

Calculated %: N 10.53.

2-Aminobenzthiazole-5,7-dicarboxylic acid. A mixture of 26.6 g of the dimethyl ester of 2--aminobenzthiazole-5,7-dicarboxylic acid and a solution of 34 g of potassium hydroxide in 1700 ml of water was boiled under reflux for 4 hours. The solution obtained was acidified with hydrochloric acid and the precipitate collected, mixed with 1000 ml of hot water, washed with hot water, and dried. The yield was 21.6 g (90.8%). The product was a colorless, crystalline powder. It was almost insoluble in the normal organic solvents, but slightly more so in pyridine. The m.p. was above 300°. For analysis, the substance was boiled with alcohol and reprecipitated twice from sodium carbonate solution.

Found %: N 11.81. Equiv. 118.0. $C_9H_6O_4N_2S$.

Calculated %: N 11.76. Equiv. 119.07.

2-Aminobenzthiazole-6-carboxylic acid. 22.2 g of the ethyl ester of 2-aminobenzthiazole-6--carboxylic acid with m.p. 239-240° [20] was boiled

for 2 hours with 500 ml of conc. HCl. The cooled solution was diluted with water, made alkaline with sodium carbonate, filtered free from the slight precipitate, made weakly acid with hydrochloric acid, and mixed with 100 ml of 10% sodium acetate solution. The precipitate was collected, washed with water, and dried. The yield was 18.2 g (94%). The colorless crystals were insoluble in the usual organic solvents, but dissolved in sodium carbonate solution. The m.p. was above 300°. For analysis, the substance was reprecipitated from sodium carbonate solution.

Found %: N 14.10. Equiv. 193.2. $C_8H_6O_2N_2S$.

Calculated %: N 14.43. Equiv. 194.0.

2-Hydrazinobenzthiazolemono- and dicarboxylic acids. 0.1 mole of the 2-aminobenzthiazolemono- or dicarboxylic acid was heated with an aqueous solution of hydrazine hydrate on an oil bath (at 120-135° in the oil) for 6-9 hours, when the intense evolution of ammonia noticeably slackened toward the end of heating. The cooled reaction mixture was poured into hydrochloric acid and the precipitate collected, washed with water, and dried. For purification, the substance was reprecipitated from sodium carbonate solution with hydrochloric acid. The 2-hydrazinobenzthiazolemono- and dicarboxylic acids obtained had m.p. above 300°, were practically insoluble in the usual organic solvents, and dissolved readily in sodium carbonate solution. They reduced an ammoniacal solution of silver nitrate even at normal temperature. The experimental conditions and analysis data are presented in the table.

SUMMARY

1. A study was made of the reaction of 2-aminobenzthiazole and its derivatives with an aqueous solution of hydrazine hydrate on heating.

2. It was shown that with 2-aminobenzthiazole, two reactions occurred at 110-120°, namely, replacement of the amino group by a hydrazino group and rupture of the thiazole ring with the formation of o-aminothiophenol, which was readily oxidized to 2,2'-diaminodiphenyl disulfide. Under these conditions, 2-amino-6-ethoxy- and 2-amino-5,6-dimethylbenzthiazole did not react with hydrazine hydrate.

3. It was established that the reaction of 2-aminobenzthiazole-6-mono-, 5,7-, 5,6-, and 6,7-dicarboxylic acids with an aqueous solution of hydrazine hydrate with heating gave good yields of the corresponding 2-hydrazinobenzthiazolecarboxylic acids.

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INTRAMOLECULAR HYDROGEN BOND AND DIPOLE MOMENTS

OF ORGANIC COMPOUNDS

IV. NITRO- AND ACETYLACETANILIDES

A. E. Lutskii and B. P. Kondratenko

Khar'kov Polytechnical Institute

Original article submitted March 20, 1958

As was shown previously [1], the presence of an intramolecular hydrogen bond leads to certain peculiarities in the relations of the dipole moments of isomers of di- and monosubstituted benzenes, measured in benzene and dioxane as solvents, observed and calculated under conditions of free rotation of noninteracting groups [2]. These peculiarities are caused by the presence of a cis form in ortho isomers due to an intramolecular hydrogen bond and the absence of association with molecules of electron-donor solvents due to a hydrogen bond.

On the basis of data on the absorption spectra in the near-ultraviolet, the melting points and other properties of nitro- and acyl-substituted acetanilides, it was proposed [3] that, in the ground state, their ortho isomers contained an intramolecular hydrogen bond of the type:
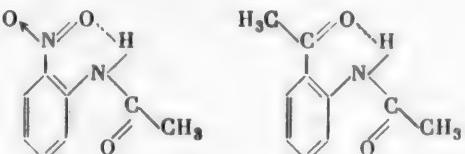
It seemed interesting to examine the dipole moments of isomeric acyl- and nitroacetanilides in order to determine the character of the effect of this bond on the characteristics of the dipole moments. In this connection, we measured the dielectric permeability $\epsilon_{1,2}$ and density $d_{1,2}$ at 25° of acetanilide, p-methylacetanilide, and of o-, m-, and p-nitro- and acetylacetanilides in benzene (apart from the extremely sparingly soluble p--nitroacetanilide) and dioxane as solvents. The acetanilides studied* were synthesized and purified according to literature directions [4], and the procedures for measurement and purification of solvents were described in detail in [5]. The results of measuring $\epsilon_{1,2}$ and $d_{1,2}$ are given in Table 1, and the calculated values of $P_{2\infty}$ (according to Hedestrand [6]), P_{E+A}, and the dipole moments μ (in D) are in Table 2.

The value obtained for the moment of acetanilide in benzene was 0.32 D lower and, on the other hand, that in dioxane was somewhat higher (by 0.09 D) than the values presented in the literature [7,8]; it was close to that of 4-N-acetyldiphenyl (3.83 D) [7]. Calculation of the moment of acetanilide with the presence of a flat trans-form at the NHCO-group [9] and this coplanar with the benzene ring, using the angles from x-ray structural analysis of this compound [10], and the moments of the bonds from data in [9], led to the value of 3.57 D, i.e., almost agreeing with the observed value (3.69 D).

The dipole moments of nitro- and acetylacetanilides showed all the previously reported peculiarities in the relations of the values of the moments [1] characteristic of compounds with an intramolecular hydrogen bond in the ortho isomers. Thus, the moments of o-nitro- and o-acetylacetanilides were anomalously low in comparison with those of the para isomers. In contrast to the latter, they were low in comparison with the values of the

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* The acetylacetanilides were synthesized by V. V. Dorofeev.

TABLE 1

$d_{1,2}$ and $\epsilon_{1,2}$ of Substituted Acetanilides

Compound	In benzene			In dioxane		
	N_2 (in mole %)	$d_{1,2}$	$\epsilon_{1,2}$	N_2 (в мол. %)	$d_{1,2}$	$\epsilon_{1,2}$
C$_6$H$_5$NHCOCH$_3$	0.0642	0.87395	2.2860	0.0674	1.02745	2.2442
	0.1344	0.87421	2.2993	0.1272	1.02751	2.2592
	0.2365	0.87455	2.3202	0.2025	1.02759	2.2777
	0.3060	0.87479	2.3385	0.2808	1.02769	2.2971
	0.3737	0.87503	2.3558	0.3371	1.02774	2.3107
C$_6$H$_4$(NO$_2$)NHCOCH$_3$ o-	0.0564	0.87405	2.2766	0.0370	1.02756	2.2302
	0.1131	0.87441	2.2796	0.0806	1.02777	2.2341
	0.1764	0.87485	2.2827	0.1382	1.02805	2.2395
	0.2691	0.87545	2.2874	0.1860	1.02829	2.2443
	0.3320	0.87592	2.2903	0.2168	1.02845	2.2465
m-	0.0107	0.87373	2.2776	0.0500	1.02761	2.2474
	0.0219	0.87377	2.2811	0.0819	1.02773	2.2598
	0.0303	0.87381	2.2849	0.1161	1.02790	2.2734
	0.0473	0.87388	2.2909	0.1541	1.02810	2.2895
	—	—	—	0.1899	1.02834	2.3037
p-	—	—	—	0.0161	1.02750	2.2216
	—	—	—	0.0269	1.02757	2.2303
	—	—	—	0.0401	1.02765	2.2399
	—	—	—	0.0525	1.02772	2.2495
	—	—	—	0.0632	1.02778	2.2565
C$_6$H$_4$(COCH$_3$)NHCOCH$_3$ o-	0.0104	0.87373	2.2758	0.0105	1.02745	2.2298
	0.0249	0.87380	2.2781	0.0237	1.02749	2.2324
	0.0404	0.87385	2.2801	0.0399	1.02753	2.2361
	0 0523	0.87393	2.2823	0.0527	1.02757	2.2383
	0.0665	0.87400	2.2848	0.0623	1.02760	2.2402
m-	0.0191	0.87379	2.2780	0.0305	1.02747	2.2359
	0.0333	0.87385	2.2815	0.0584	1.02753	2.2419
	0.0512	0.87396	2.2853	0.0862	1.02762	2.2496
	0.0719	0.87408	2.2896	0.1207	1.02768	2.2582
	0.0870	0.87416	2.2930	0.1684	1.02780	2.2701
p-	0.0192	0.87375	2.2787	0.0272	1.02749	2.2368
	0.0323	0.87383	2.2825	0.0568	1.02757	2.2469
	0.0365	0.87383	2.2834	0.0892	1.02765	2.2585
	0.0455	0.87387	2.2861	0.1223	1.02773	2.2709
	0.0496	0.87388	2.2889	0.1491	1.02780	2.2812
C$_6$H$_4$(CH$_3$)NHCOCH$_3$	0.0199	0.87375	2.2780	0.0539	1.02747	2.2400
	0.0496	0.87384	2.2838	0.0959	1.02751	2.2498
	0.0818	0.87393	2.2906	0.1374	1.02756	2.2597
	0.1228	0.87405	2.2991	0.1637	1.02758	2.2657
	0.1557	0.87414	2.3055	0.1907	1.02761	2.2722

Note. N_2 is the mole fraction of the second component, $\epsilon_{1,2}$ is the dielectric permeability of the mixture, and $d_{1,2}$ is the density of the mixture 1,2.

moments of the original monosubstituted derivatives. For comparison of the values of the moments obtained with those calculated under conditions of free rotation of noninteracting functional groups by Fuchs' formula [2], it is necessary to know the angle of inclination of the resulting moment of the N-acetyl group to the direction of the $C_{ar}-N$ bond. In order to determine this angle, the moment of p-N-acetylaminotoluene was determined; here, an electron repelling (in the ring) effect has been accepted for the N-acetyl group, judging by the character of the directing action of this group in substitution reactions in the ring and the absorption spectra [11]. Table 2 gives the calculated values of the dipole moments of nitro- and acetylacetanilides under the conditions indicated and using the value obtained for the angle of inclination of the resulting moment of the N-acetyl group (100°). As was also observed with other compounds with an intramolecular hydrogen bond in the ortho isomers, the dipole moments of o-nitro- and o-acetylacetanilides, in contrast to those of the para isomers, were much lower than the calculated values. The slightly greater-than-normal reduction in moment in comparison with the calculated value in the

TABLE 2

Dipole Moments of Acetanilides

Compound	$P_{2\infty}$		P_{E+A}	$\mu \cdot 10^{18}$		$\Delta\mu = \mu_D - \mu_B$	$\mu \cdot 10^{18}$, calc. according to [2] for free rotation of the groups
	benzene	dioxane		benzene	dioxane		
$C_6H_5NHCOCH_3$	323.5	394.0	43.3	3.69	4.11	+0.42	—
$C_6H_4(CH_3)NHCOCH_3$-p	342.3	380.1	46.4	3.78	4.02	+0.24	—
$C_6H_4(COCH_3)NHCOCH_3$ {o-	283.0	326.9	54.2	3.32	3.63	+0.31	4.98
m-	370.5	415.6	54.2	3.91	4.18	+0.27	4.60
p-	540.1	602.3	54.2	4.84	5.15	+0.31	4.47
$C_6H_4(NO_2)NHCOCH_3$ {o-	115.3	172.1	51.2	1.76	2.42	+0.66	5.85
m-	577.6	625.0	51.2	5.04	5.26	+0.22	5.16
p-	—	1091.4	51.2	—	7.09	—	4.92

Note. $P_{2\infty}$ is the polarization at infinite dilution, μ_D is the dipole moment in dioxane, and μ_B is the dipole moment in benzene.

case of m-acetylacetanilide may be explained by a certain hindrance to free rotation of the groups due to the possibility of predominant orientation of the hydrogen of the N-acetylamino group toward the oxygen of the carbonyl group in this isomer, as has also been proposed for other meta isomers, for example, for certain substituted phenols [12]. The noticeable increase in the observed dipole moment of para isomers in comparison with the calculated values indicates that both in the activated and in the basic states there prevails conjugation of the p-electrons of the nitrogen of the N-acetylamino group with the π-electrons of the ring of type (A) and not conjugation of these nitrogen electrons with the π-electrons of the carbonyl group of type (B), as proposed in [9].
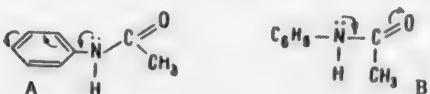
The presence of an intramolecular hydrogen bond in the ortho isomers considered also follows from a comparison of the observed dipole moments with those calculated for configurations (I) and (II). It was found [5] that for o-acetylacetanilide the observed moment almost coincided with that calculated for the cis-form (I), fixed by the presence of an intramolecular hydrogen bond in the molecule. A somewhat higher moment for o-nitroacet-

$$\mu \cdot 10^{18} = 0.45D$$
(I)

$$\mu \cdot 10^{18} = 5.69D$$
(II)
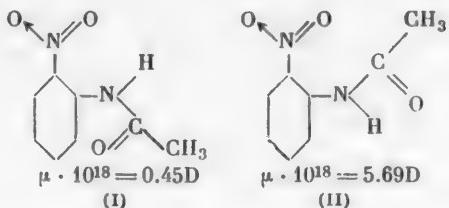
anilide than the value for configuration (I) may be connected with either a considerable effect of conjugation between the groups or the presence of some molecules with configuration (II), for example (91% cis- and 9% trans-forms).

The relations of the moments in benzene established above were also maintained in dioxane. The slightly anomalous increase in the moment in dioxane compared with that in benzene, observed with all the compounds studied, was connected with an increase in the conjugation of the nitrogen p-electrons with the π-electrons of the carbonyl of the N-acetylamino group in dioxane [9] or, what is more probable, with the formation, as in the case of phenols and amines [1], of complexes with dioxane molecules due to a hydrogen bond [9]. Then, the almost identical growth in the moment of o-nitro- and o-acetylacetanilides may be connected with either a decrease in the stability of the intramolecular hydrogen bond in dioxane or its rupture in a certain fraction of the molecules.

SUMMARY

1. The values of the dipole moments of acetanilide, p-methylacetanilide, and o-, m-, and p-nitro and acetylacetanilides were determined in benzene and dioxane at 25°.

2. On the basis of the relations of the dipole moments of isomers of di- and monosubstituted benzenes, observed and calculated for various configurations and for free rotation of noninteracting functional groups, the presence of an intramolecular hydrogen bond in o-nitro- and o-acetylacetanilides was confirmed.

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*Original Russian pagination. See C.B. translation.

DIPOLE MOMENTS OF N-NITROSOMETHYLANILINE
AND ITS NITRO DERIVATIVES

A. E. Lutskii and B. P. Kondratenko

Khar'kov Polytechnical Institute

Original article submitted March 20, 1958

A methylamino group possesses electron donor properties with respect to an aromatic ring. It seemed interesting to determine the character of the interaction of the p-electrons of this group with the π-electrons of the ring when the amino hydrogen was replaced by a nitroso group. For this purpose, we determined the dipole moments of N-nitrosomethylaniline and its ortho-, meta-, and para-nitro derivatives in benzene and dioxane as solvents. These compounds were prepared and purified according to literature directions [1]. The synthesis and purification of the substances, and also the procedure for determining the dielectric permeability $\epsilon_{1,2}$ and the density $d_{1,2}$ were described in detail in [2]. The measured values of the dielectric permeability and the density of solutions of the substances investigated in the given solvents at 25° are presented in Table 1, and the calculated values of $P_{2\infty}$, P_{E+A}, and the dipole moments μ (in D), are in Table 2.

TABLE 1

$d_{1,2}$ and $\epsilon_{1,2}$ of Solutions of Nitrosomethylanilines in Benzene and Dioxane

Compound	In benzene			In dioxane		
	N_2 (mole %)	$d_{1,2}$	$\epsilon_{1,2}$	N_2 (mole %)	$d_{1,2}$	$\epsilon_{1,2}$
N-Nitrosomethylaniline	0.0318	0.87383	2.2797	0.0342	1.02747	2.2177
	0.0627	0.87395	2.2854	0.0697	1.02752	2.2259
	0.0943	0.87408	2.2914	0.1059	1.02758	2.2346
	0.1258	0.87422	2.2973	0.1425	1.02763	2.2425
	0.1568	0.87435	2.3027	0.1792	1.02769	2.2503
o-Nitro-N-nitroso-methylaniline	0.0226	0.87389	2.2841	0.0186	1.02751	2.2370
	0.0399	0.87402	2.2926	0.0490	1.02765	2.2532
	0.0531	0.87414	2.2996	0.0834	1.02783	2.2729
	0.0665	0.87426	2.3056	0.1113	1.02797	2.2876
	0.0840	0.87442	2.3142	0.1436	1.02813	2.3046
m-Nitro-N-nitrosom-ethylaniline	0.0228	0.87383	2.2784	0.0436	1.02754	2.2362
	0.0462	0.87403	2.2832	0.0860	1.02775	2.2443
	0.0756	0.87427	2.2890	0.1319	1.02793	2.2539
	0.0935	0.87443	2.2924	0.1892	1.02817	2.2646
	0.1137	0.87459	2.2958	0.2379	1.02837	2.2752
p-Nitro-N-nitroso-methylaniline	0.0323	0.87389	2.2797	0.0293	1.02753	2.2336
	0.0552	0.87407	2.2839	0.0558	1.02765	2.2388
	0.0750	0.87427	2.2875	0.0828	1.02777	2.2444
	0.1020	0.87447	2.2921	0.1115	1.02790	2.2504
	0.1234	0.87468	2.2963	0.1488	1.02806	2.2582

Note: $\epsilon_{1,2}$ is the dielectric permeability of the mixture, $d_{1,2}$ is the density of the mixture, and N_2 is the mole fraction of the second component.

TABLE 2

Dipole Moments of N-Nitrosomethylaniline and its Nitro Derivatives

Compound	P_{∞}		P_{E+A}	$\mu \cdot 10^{18}$		$\Delta\mu = \mu_D - \mu_B$	$\mu \cdot 10^{18}$ calculated for free rotation
	in benzene	in dioxane		in benzene	in dioxane		
$C_6H_5N(NO)CH_3$	307.9	354.7	42.1	3.58	3.88	+0.30	—
$C_6H_4(NO_2)N(NO)CH$ o-	743.1	817.2	50.0	5.79	6.09	+0.30	7.24
m-	322.9	330.7	50.0	3.63	3.68	+0.05	4.05
p-	302.9	341.6	50.0	3.49	3.76	+0.27	2.11

Note: $P_{2\infty}$ is the polarization at infinite dilution, μ_D is the dipole moment in dioxane, and μ_B is the dipole moment in benzene.

The value obtained for the moment of N-nitrosomethylaniline almost coincides with the literature value (3.62 D) [3], and lies between those of completely aliphatic and completely aromatic N-nitroso compounds: actually, $(CH_3)_2NNO$ has a dipole moment of 3.98 D, and $(C_6H_5)_2NNO$, 3.39 D. Evidently, replacement of each of the methyl groups by a phenyl produces a decrease in the dipole moment of approximately 0.3 D. The values of the moments of nitro-N-nitrosomethylanilines differ not only quantitatively, but also qualitatively from those of the original nitromethylanilines. Thus, while for the latter the moment changes in the order p > m > o, for the former the relation of the dipole moments is the reverse, and in contrast to the nitromethylanilines, the moments of the m- and p-nitro-N-nitrosomethylanilines are very similar to each other in value. The relation of the dipole moments of isomeric nitro-N-nitrosomethylanilines is similar to that for nitrophenyl isocyanates [4].

On the basis of data for the dipole moments of other compounds, the angle of inclination of the resultant moment of the N-nitrosomethylamino group to the $C_{ar}-N$ bond may be taken as equal to 148° [3]. With this angle of inclination, the values of the dipole moments of the isomeric nitro-N-nitrosomethylanilines may be explained satisfactorily if it is assumed that replacement of the hydrogen on the nitrogen of the methylamino group by a nitroso group does not change its electron-donor character qualitatively. In this case, the calculated values of the moments under conditions of free rotation of noninteracting functional groups, using Fuchs' method [4] (Table 2), change like the observed values in the series o > m > p, and the latter deviate from the calculated values qualitatively and quantitatively like many other compounds of a similar type. Thus, for p-nitro-N-nitrosomethylaniline, the high value of μ_{obs} as compared with μ_{calc} is connected with the effect of conjugation of the groups, and the low value of μ_{obs} compared with μ_{calc} for o-nitro-N-nitrosomethylaniline is due to steric repulsion of the highly polar nitro and nitroso groups. From this point of view, the decrease in dipole mo-

$C_6H_5 \leftarrow N \rightarrow N\!\!=\!\!O$
$\uparrow$
CH_3

ment in going from aliphatic to aromatic nitrosoamines, indicated above, is apparently caused not only by a possible change in the angle of inclination of the resultant moment of the group [3], but also by the fact that phenyl groups, in contrast to alkyls, attract electrons from the nitrogen of the amino group, which promotes a decrease in the moment of the N-nitrosomethylamino group.
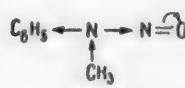
With unsubstituted N-nitrosomethylaniline and its ortho- and para-nitro substituted derivatives, an increased growth in the dipole moment was observed in dioxane, as compared with that in benzene. Evidently an anomalous dioxane effect, as was also observed in the case of nitro-N,N-dimethylanilines [2], is also possible when the formation of complexes between molecules of the components due to a hydrogen bond is absent. It is possible that for compounds with several highly polar functional groups the anomalous growth in their moment in dioxane is connected with polarization of molecules of the latter by their suitable orientation during temporary accumulations at the polar groups of the molecules of the dissolved substance.

SUMMARY

1. The values of the dipole moments of N-nitrosomethylaniline and its ortho-, meta-, and para-nitro substituted derivatives in benzene and dioxane as solvents were determined.

2. The values of the moments of nitro-N-nitrosomethylanilines may be explained satisfactorily, starting

from the hypothesis that, on replacement of the hydrogen at the nitrogen of the methylamine group by a nitroso group, the electron-donor character of the former is retained.

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POLYENE COMPOUNDS

VIII. REACTIONS OF SOME ACETALS WITH UNSATURATED ETHERS

B. M. Mikhailov and L. S. Povarov

Institute of Organic Chemistry, Academy of Sciences, USSR

The reactions of acetals with α,β-unsaturated ethers have been described in a series of works [1-4]. Recently, it was found that acetals are capable of reacting with ethers containing conjugated double bonds (alkoxydienes) to form products of 1,4-addition to the diene [4-6]. In the present work, we used this reaction for the synthesis of some derivatives of terpene aldehydes.

It was found that, in the presence of zinc chloride, the acetal of citral (I) reacted with 1-ethoxy-3-methylbutadiene-1,3 (II) to form the acetal of 5-ethoxy-3,7,11-trimethyldodecatrien-2,6,10-al-1 (III) (a derivative of an aldehyde of the sesquiterpene series, farnesal) and the acetal of 5,9-diethoxy-3,7,11,15-tetramethylhexadecatetraen-2,6,10,14-al-1 (IV) (a derivative of a diterpene aldehyde) by the scheme
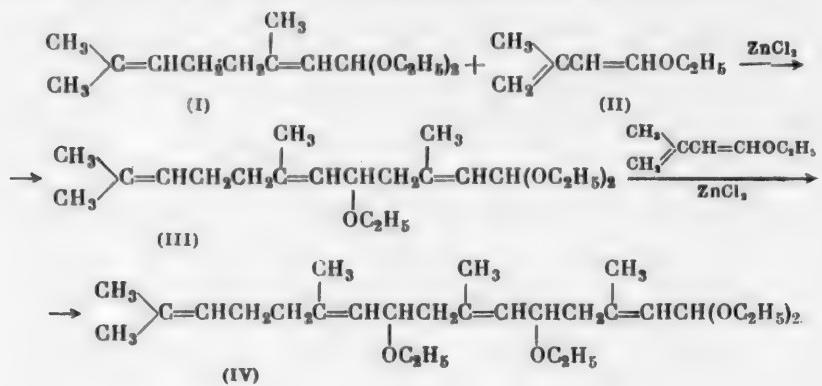
We used the reaction of α,β-unsaturated ethers with acetals to synthesize the acetal of diethoxycitronellal (VIII). The acetal of 3-methylcrotonaldehyde (VI) was condensed with isopropenyl ethyl ether (V) in the presence of zinc chloride, and this yielded the ketal of 4-ethoxy-6-methylhepten-6-one-2 (VII). The latter was condensed with vinyl ethyl ether to give the acetal of 3,5-diethoxy-3,7-dimethylocten-6-al-7 (acetal of diethoxycitronellal) (VIII).

$$\rightarrow \underset{CH_3}{\overset{CH_3}{>}}C=CHCHCH_2\overset{\overset{CH_3}{|}}{C}CH_2CH(OC_2H_5)_2$$
$$\underset{\underset{OC_2H_5}{|}}{\quad} \underset{\underset{OC_2H_5}{|}}{\quad}$$

(VIII)
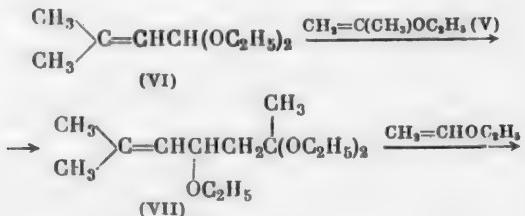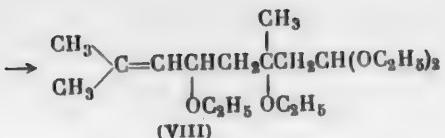
The starting 1-ethoxy-3-methylbutadiene-1,3 was obtained by the method we developed by the action of catalytic amounts of p-toluenesulfonic acid in quinoline on 1,1,3-triethoxy-3-methylbutane (IX). This method was also suitable for the preparation of 1-ethoxybutadiene-1,3 from 1,1,3-triethoxybutane. In the preparation of 1,1,3-triethoxy-3-methylbutane by condensation of acetone ketal with vinyl ethyl ether, it was established that the addition products of two and three molecules of vinyl ethyl ether to the ketal, 1,1,3,5-tetraethoxy-5-methylhexane (X) and 1,1,3,5,7-pentaethoxy-7-methyloctane (XI) were formed. These compounds were also obtained by condensation of (IX) with vinyl ethyl ether.

$$\underset{CH_3}{\overset{CH_3}{>}}CCH_2CH(OC_2H_5)_2 \xrightarrow{CH_2=CHOC_2H_5} \underset{CH_3}{\overset{CH_3}{>}}CCH_2CHCH_2CH(OC_2H_5)_2 \xrightarrow{CH_2=CHOC_2H_5}$$

(IX) (X)

$$\rightarrow \underset{CH_3}{\overset{CH_3}{>}}CCH_2CHCH_2CHCH_2CH(OC_2H_5)_2$$
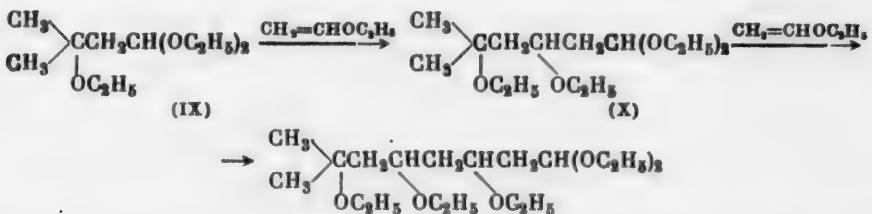
In preparing the starting α,β-unsaturated ethers, we developed a convenient method of synthesizing them by the action of catalytic amounts of p-toluenesulfonic acid in quinoline on the corresponding acetals and ketals.

EXPERIMENTAL

1. 1,1,3-Triethoxy-3-methylbutane (IX) and 3-ethoxy-3-methylbutanal. To 67 g of acetone ketal, containing 0.1 g of BF_3 etherate, at 50° was added 18 g of vinyl ethyl ether, dropwise, and then the mixture was kept at 50° for 15 minutes. The catalyst was neutralized by stirring (3 hours) with anhydrous sodium carbonate. Distillation yielded 42 g of the original acetone ketal and 26 g of 1,1,3-triethoxy-3-methylbutane (67.4% on the acetal which reacted).

B.p. 202-204° at 760 mm, 84-85° at 12 mm, d^{20}_4 0.8824, $n^{20}D$ 1.4164, MR_D 58.18; calc. 57.93.

According to [7]: b.p. 78° at 7 mm, d^{20}_4 0.8813, $n^{20}D$ 1.4145.

Together with 1,1,3-triethoxy-3-methylbutane, 1,1,3,5-tetraethoxy-5-methylhexane, and 1,1,3,5,7-pentaethoxy-7-methyloctane, were formed and we also obtained these compounds by condensation of 1,1,3-triethoxy-3-methylbutane with vinyl ether (see below).

Hydrolysis of 26 g of 1,1,3-triethoxy-3-methylbutane with 2% HCl (50 ml) in the cold yielded 12.5 g (73.5%) of 3-ethoxy-3-methylbutanol.

B.p. 147-148° at 760 mm, d^{20}_4 0.8980, $n^{20}D$ 1.4192, MR_D 36.63; calc. 36.18.

Found %: C 64.60, 64.56; H 10.81, 10.90. $C_7H_{14}O_2$.

Calculated %: C 64.57; H 10.83.

2. 1,1,3,5-Tetraethoxy-5-methylhexane (X) and 1,1,3,5,7-pentaethoxy-7-methyloctane (XI). To 32 g of 1,1,3-triethoxy-3-methylbutane, containing 0.1 g of BF_3 etherate, at 48-50° was added 11 g of vinyl ethyl ether, dropwise. The reaction was carried out as in the previous experiment. We obtained 12 g (28.9%) of 1,1,3,5-tetraethoxy-5-methylhexane.

B.p. 133-134° at 13 mm, d^{20}_4 0.9047, $n^{20}D$ 1.4268, MR_D 78.41; calc. 78.042.

Found %: C 64.89, 65.14; H 11.70, 11.61. $C_{15}H_{32}O_4$.

Calculated %: C 65.17; H 11.67.

We also isolated 7.5 g (27%) of 1,1,3,5,7-pentaethoxy-7-methyloctane.

B.p. 121-123° at 2 mm, d^{20}_4 0.9169, n^{20}D 1.4330, MR$_D$ 98.79; calc. 98.16.

Found %: C 65.20, 65.20; H 11.50, 11.41. $C_{19}H_{40}O_5$.

Calculated %: C 65.47; H 11.56.

3. 1-Ethoxy-3-methylbutadiene-1,3 (II). 31 g of 1,1,3-triethoxy-3-methylbutane was added dropwise to a solution of 0.1 g of p-toluenesulfonic acid in 2 ml of quinoline, heated to 220-240° in a distillation flask. The decomposition product, which distilled at a temperature of no higher than 135°, was collected over 4% sodium carbonate solution, washed with water, and dried with potassium carbonate. We obtained 9.5 g of 1-ethoxy-3-methylbutadiene-1,3 (53.4%).

B.p. 135-137° at 760 mm, 78-79° at 116 mm, d^{20}_4 0.8338, n^{20}D 1.4636, MR$_D$ 37.04; calc. 35.24.

Similarly, from 32 g of 1,1,3-triethoxybutane, we obtained 11 g (66%) of 1-ethoxybutadiene-1,3 with b.p. 112-115°, n^{20}D 1.4602.

The conversion of 1,1,3-triethoxy-3-methylbutane into ethoxyisoprene (b.p. 75-77° at 90 mm) was recently achieved with $MgHPO_4$ at 350° [7].

4. Citral acetal (I). 30 g of citral was dissolved in 95 g of orthoformic ester and 60 g of anhydrous alcohol. To the solution was added 0.5 ml of a saturated alcohol solution of hydrogen chloride with cooling, and the mixture allowed to stand for 5 days; when the catalyst had been neutralized by stirring with 100 ml of 5% sodium carbonate solution, 100 ml of ether was added, and the ether solution washed three times with 5% sodium carbonate solution and water, and dried over sodium sulfate.

Distillation yielded 38 g (84.4%) of citral acetal.

B.p. 84-85° at 2.5 mm, d^{20}_4 0.8732, n^{20}D 1.4508, MR$_D$ 69.77; calc. 69.20.

Found %: C 74.50, 74.23; H 11.57, 11.65. $C_{14}H_{26}O_2$.

Calculated %: C 74.28; H 11.58.

5. Reaction of citral acetal with ethoxyisoprene. At a temperature of 20-23°, 12 g of ethoxyisoprene was added to 59 g of citral acetal containing 2 ml of a 10% solution of $ZnCl_2$ in acetic acid. After the addition, the mixture was stirred for 10 minutes, and then the catalyst was neutralized by washing with 4% sodium hydroxide solution, 100 ml of ether added, the ether solution washed with 4% sodium hydroxide solution and water, and dried with potassium carbonate. Fractionation in vacuum yielded unreacted original citral acetal (38 g) and two substances: a) the acetal of 5-ethoxy-3,7,11-trimethyldodecatrien-2,6,10-al-1 (ethoxyfarnesal acetal) (III) in a yield of 16 g (47.3%).

B.p. 139-140° at 2 mm, d^{20}_4 0.9019, n^{20}D 1.4667, MR$_D$ 104.08; calc. 107.71.

Found %: C 74.59, 74.70; H 11.32, 11.39. $C_{21}H_{38}O_3$.

Calculated %: C 74.50; H 11.32.

b) The acetal of 5,9-diethoxy-3,7-11,15-tetramethylhexadecatetraen-2,6,10,14-al-1 (IV) in a yield of 4 g (17.8%).

B.p. 179-181° at 2 mm, d^{20}_4 0.9147, n^{20}D 1.4780.

Found %: C 74.47, 74.56; H 11.23, 11.11. $C_{28}H_{50}O_4$.

Calculated %: C 74.62; H 11.18.

7. Condensation of 3-methylcrotonaldehyde acetal (VI) with isopropenyl ethyl ether. At a temperature of 40°, 9 g of isopropenyl ethyl ether was added dropwise to 17 g of 3-methylcrotonaldehyde acetal containing 1 ml of a 5% ether solution of $ZnCl_2$. The mixture was kept at 40° for 1 hour, cooled, diluted with ether, washed with 2% sodium hydroxide solution, and dried over potassium carbonate. We obtained 14.5 g (60%) of 4-ethoxy-6-methylhepten-5-one-2 ketal (VII).

B.p. 83-84° at 3 mm, d^{20}_4 0.8893, n^{20}D 1.4355, MR$_D$ 71.31; calc. 71.77.

Found %: C 68.60, 68.70; H 11.59, 11.64. $C_{14}H_{28}O_3$.

Calculated %: C 68.81; H 11.55.

8. Condensation of 4-ethoxy-6-methylhepten-5-one-2 ketal with vinyl ethyl ether. To 35 g of 4-ethoxy--6-methylhepten-5-one-2 diethylketal, containing 0.03 g of BF$_3$ etherate, at 40-50°, was added 4 g of vinyl ethyl ether. The mixture was stirred for 15 minutes and then treated as in the previous experiment. We obtained 2 g of 3,5-diethoxy-3,7-dimethylocten-6-al-1 acetal (diethoxycitronellal acetal) (VIII).

B.p. 124-127° at 2 mm, n^{20}D 1.4530.

Found %: C 68.97, 69.01; H 10.90, 10.83. $C_{18}H_{36}O_4$.

Calculated %: C 68.30; H 11.46.

9. Preparation of isopropenyl ethyl and propenyl ethyl ethers. 120 g of diethyl ketal, 0.1 g of p-toluene-sulfonic acid, and 4 ml of quinoline were heated on a rectification column; a mixture of isopropenyl ethyl ether and alcohol distilled at a vapor temperature of 55-70°. Washing with 2% sodium carbonate solution, and drying with potassium carbonate gave 70 g (89%) of isopropenyl ethyl ether with b.p. 61-62°, n^{20}D 1.3941. When the diethyl acetal of propanal was cleaved under the same conditions, propenyl ethyl ether was obtained in 80% yield.

SUMMARY

1. Citral acetal reacted with 1-ethoxy-3-methylbutadiene-1,3 with the formation of higher terpene derivatives.

2. Successive condensations of 3-methylcrotonaldehyde acetal with isopropenyl ethyl and vinyl ethyl ethers yielded ethoxycitronellal acetal.

3. The action of catalytic amounts of p-toluenesulfonic acid in quinoline on various alkoxyalkanes led to elimination of the elements of alcohol with the formation of unsaturated ethers.

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DIRECT AMIDATION OF CARBOXYLIC ACIDS

I. N. Zhmurova, I. Yu. Voitsekhovskaya and A. V. Kirsanov

Institute of Organic Chemistry, Academy of Sciences, UkrSSR

At the present time, two methods are known for the direct amidation of carboxylic acids, and these are heating carboxylic acids under drastic conditions (180-220°) with amides of carboxylic acids, amides of sulfonic acids [1], or amides of phosphoric acid [2] and the interaction of carboxylic acids with sulfamide and substituted sulfamides [3] in pyridine solution, which proceeds with high yields under mild conditions (100-110°). Amides of sulfonic acids do not amidate carboxylic acids in pyridine solution, even at 150°. In the absence of pyridine, sulfamide amidates carboxylic acids with very low yields. The mechanism of the amidation of carboxylic acids by amides of sulfonic acids at 180-220° has not been elucidated, but the mechanism of amidation of carboxylic acids by sulfamide has been established quite strictly [3]. In any case, there is no doubt that the mechanisms of these two reactions are quite different.

In this work, an attempt was made to extend the application of the direct amidation of carboxylic acids by the second method, i.e., under mild conditions in pyridine solution, and the problem of amidation under drastic conditions was not considered.

The trianilide of phosphoric acid phenylamidates carboxylic acids with the same ease as diphenylsulfamide, and probably by the same mechanism [4], but many amides of phosphoric acid, very similar in structure to phosphoric acid trianilide, for some reason do not amidate carboxylic acids at all. It is particularly strange that certain homologs and analogs of the trianilide of phosphoric acid, for example, the tri-p-toluidide of phosphoric acid, triaminophosphazosulfonophenyl, trianilinophosphazosulfonophenyl, etc. [4], do not react with carboxylic acids on heating in pyridine solution.

It seemed interesting to determine whether amides of monobasic phosphoric acids would show amidating properties in pyridine solution, or whether amidation under mild conditions required the presence in the molecule of two amide groups, in which there must be at least one "free" hydrogen atom attached to the nitrogen atom of the amide group [3]. As subjects for the experiments, we chose amides of the type $(RO)_2PONH_2$ and Ar_2PONH_2 and their N-substituted derivatives.

The experiments showed that amides of diethyl, diisopropyl and diphenyl phosphates and the amide of diphenyl thiophosphate did not amidate carboxylic acids on boiling in pyridine solution. Since these experiments gave negative results, they are not described in the experimental part.

Carboxylic acids were not amidated either by the amide, dimethylamide and anilide of diphenylthiophosphinic acid and the anilide of diphenylphosphinic acid, but were amidated by the amide and dimethylamide of diphenylphosphinic acid. Amidation by the amide of diphenylphosphinic acid proceeded particularly smoothly by the scheme

$$RCOOH + (C_6H_5)_2PONH_2 \longrightarrow RCONH_2 + (C_6H_5)_2POOH.$$

The reaction was complete in 4-5 hours, when equimolecular amounts of acid and amide were boiled in pyridine or dioxane, i.e., it proceeded considerably more slowly than amidation by amides of sulfuric acid [3].

The reaction mechanism undoubtedly differed from that for the amidation of carboxylic acids by sulfamides since the amidating molecules had only one amido group; in addition, the dimethylamide of diphenylphosphinic acid lacks a "free" hydrogen at the nitrogen, and this excludes the possibility of the intermediate formation of N-acyl derivatives of the amidating molecule, whose formation was quite strictly demonstrated in the case of amidation by sulfamides [3]. It is more probable than the anion of the carboxylic acid was added to the phosphorus atom, analogous to the addition of a hydroxyl during hydrolysis, i.e., according to the scheme:

$$(C_6H_5)_2\overset{+\delta}{P}=\overset{-\delta}{O} + RCOO^- \longrightarrow (C_6H_5)_2\overset{\overset{O^-}{|}}{P}-OCOR \longrightarrow RCON(CH_3)_2 + (C_6H_5)_2POO^-$$
$$\underset{N(CH_3)_2}{|} \qquad\qquad \underset{N(CH_3)_2}{|}$$
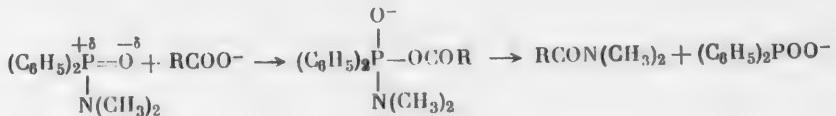
This hypothesis was confirmed by the fact that the amidating capacity of amides of diphenylphosphinic and diphenylthiophosphinic acids corresponded to the ease of their hydrolysis, i.e., the capacity for adding a hydroxyl.

The amide of diphenylphosphinic acid was hydrolyzed remarkably easily (see below) and amidated carboxylic acids smoothly. The dimethylamide of diphenylphosphinic acid was hydrolyzed with considerably more difficulty (see below), and its amidating properties were weakly expressed: benzoic, p-chlorobenzoic, and m-nitrobenzoic acids were not amidated at all, the dimethylamide of p-nitrobenzoic acid was obtained in a yield of about 60%, and only 3,5-dinitrobenzoic acid gave a dimethylamide in 96% yield. Thus, the presence of electronegative groups in the ring undoubtedly facilitates the amidation of aromatic carboxylic acids, as is also observed in amidation by sulfamides [3]; this is also observed for the unsubstituted amide of diphenylphosphinic acid, which amidated benzoic acid in 31% yield and benzoic acids with electronegative substituents in 60-85% yields.

The amides of diphenylphosphinic and diphenylthiophosphinic acids listed above, which did not amidate carboxylic acids, were hydrolyzed by water with very great difficulty (see below), but hardly with any more difficulty than the symmetrical diphenylsulfamide, which amidated carboxylic acids very readily and almost quantitatively [3]. Thus, one can only consider the parallelism between amidating capacity and hydrolyzability for amides of monotypic acids and not for amides derived from acids of various types, since the reaction mechanisms are undoubtedly different in this case. It is even possible that the mechanisms of amidation by the amide and the dimethylamide of diphenylphosphinic acid are not completely identical, since the former amidates in pyridine solution with considerably better yields than in dioxane, and the latter, the reverse (see Experimental). Sulfamide amidates p-nitrobenzoic acid in pyridine solution in almost quantitative yield [3], and in dioxane in only 36% yield, with the amide obtained in a very impure state.

The amides, dimethylamides, and anilides of diphenylphosphinic and diphenylthiophosphinic acids, with the exception of the anilide of diphenylphosphinic acid [5], have not been described in the literature, and we were, therefore, forced to synthesize them. They were all obtained by the action of ammonia or the appropriate amine on the acid chlorides of diphenylphosphinic and diphenylthiophosphinic acids.

The acid chloride of diphenylphosphinic acid was very readily hydrolyzed by water and atmospheric moisture to diphenylphosphinic acid. Therefore, during the action of an aqueous solution of ammonia, the acid chloride was partially hydrolyzed and the reaction gave a mixture of the amide of diphenylphosphinic acid and the ammonium salt of diphenylphosphinic acid. The yield of amide was 60%, and the yield of phosphinic acid, 30%. Diphenylphosphinic acid may be reconverted readily into the acid chloride by the action of phosphorus pentachloride. The reaction of the acid chloride with dry gaseous ammonia was accompanied by the formation of tarry side products, which were very difficult to remove. Here, the yield of amide also did not exceed 60%, and the quality of the product was much worse than in the reaction with aqueous ammonia. The dimethylamide of diphenylphosphinic acid could not be obtained by the action of an aqueous solution of dimethylamine on the acid chloride of diphenylphosphinic acid. The dimethylamide could be obtained in 90% yield with anhydrous dimethylamine in benzene solution. The acid chloride of diphenylthiophosphinic acid was much more stable to the action of water and atmospheric moisture than the acid chloride of diphenylphosphinic acid. Therefore, the amide and dimethylamide of diphenylthiophosphinic acid were obtained in very good yields by the action of aqueous solutions of ammonia and dimethylamine on the acid chloride. The anilides of diphenylphosphinic and diphenylthiophosphinic acids were obtained by the action of aniline on the acid chloride in benzene solution.

The Amides of Diphenylphosphinic and Diphenylthiophosphinic Acids

Structure	Yield (%)	Melting point	External form, crystallization solvent	%N		Solubility*			
				found	calc.	ethanol	ether	C_6H_6	CCl_4
$(C_6H_5)_2PONH_2$	60	165—167°	Needles, toluene	6.64, 6.66	6.36	++	-	-	-
$(C_6H_5)_2PON(CH_3)_2$	91	103—105	Needles, benzene + ligroine	5.50, 5.35	5.71	++	-	++	+
$(C_6H_5)_2PONHC_6H_5$	95	236—237 [5]	Needles, alcohol	cm. [5]	—	+	++	++	++
$(C_6H_5)_2PSNH_2$	99	102—104	Prisms, toluene + ligroine	5.93, 5.99	6.00	+	++	++	++
$(C_6H_5)_2PSN(CH_3)_2$	94	88—90	Prisms, alcohol	5.65, 5.73	5.36	+	++	++	++
$(C_6H_5)_2PSNHC_6H_5$	79	165—167	Prisms, alcohol	4.77, 4.81	4.53	+	-	+	+

* All the amides were readily soluble in acetone and insoluble in water and ligroine; - insoluble at boiling point; + soluble at boiling point; ++ soluble at room temperature.

The amides of diphenylphosphinic and diphenylthiophosphinic acids were colorless crystalline substances. The yields, melting points, solubilities, and analytical data for the amides are presented in the table.

The amide of diphenylphosphinic acid was very readily hydrolyzed by hot water and converted into the ammonium salt of diphenylphosphinic acid. Hydrolysis was complete when the amide was boiled with water for 2-3 minutes. The dimethylamide of diphenylphosphinic acid was hydrolyzed more slowly by boiling water. Under the action of dilute hydrochloric acid, the hydrolysis occurred at room temperature in 1-2 hours. When heated with dilute hydrochloric acid, the dimethylamide of diphenylphosphinic acid was hydrolyzed completely in 2-3 minutes. The anilide of diphenylphosphinic acid and the amide, dimethylamide, and anilide of diphenylthiophosphinic acid were not hydrolyzed by prolonged boiling with water.

EXPERIMENTAL

Amide of diphenylphosphinic acid. 0.36 mole of diphenylphosphinyl chloride [6] was added gradually with stirring and external cooling to 300 ml of a 20% aqueous solution of ammonia, at such a rate that the temperature of the reaction mixture kept within the limits of 20-30°. The precipitate of the amide of diphenylphosphinic acid formed was collected and dried in air. Acidification of the filtrate precipitated diphenylphosphinic acid; the yield was 30% and the m.p. 190-192°, which agrees with literature data [6].

Dimethylamide of diphenylphosphinic acid. A solution of 0.15 mole of diphenylphosphinyl chloride in 30 ml of dry benzene was gradually added with ice-water cooling and stirring to a solution of 0.35 mole of dimethylamine in 100 ml of dry benzene. The precipitate of dimethylamine hydrochloride was removed and washed 2 to 3 times with dry benzene. The filtrate was evaporated to dryness in vacuum on a water bath to leave the dimethylamide of diphenylphosphinic acid.

Anilide of diphenylphosphinic acid. To a solution of 0.02 mole of diphenylphosphinyl chloride in 10 ml of dry benzene was gradually added a solution of 0.04 mole of aniline in 10 ml of dry benzene, with stirring. The mixture was boiled on a water bath for 1 hour. The precipitate,

consisting of a mixture of aniline hydrochloride and the anilide of diphenylphosphinic acid, was collected, washed with benzene and water (to remove aniline hydrochloride), and dried in air.

Amide of diphenylthiophosphinic acid. 0.1 mole of diphenylthiophosphinyl chloride [6] was added gradually with stirring to 100 ml of a 20% aqueous solution of ammonia. Stirring was continued until the acid chloride had been completely converted into the crystalline amide, which required about half an hour. The precipitate was collected and dried in air.

The dimethylamide of diphenylthiophosphinic acid was obtained by the action of a 33% aqueous solution of dimethylamine on diphenylthiophosphinyl chloride, similarly to the previous experiment.

Anilide of diphenylthiophosphinic acid. A mixture of 0.01 mole of diphenylthiophosphinyl chloride, 0.02 mole of aniline, and 10 ml of benzene was boiled under reflux for 6 hours. The benzene was removed, the residue treated with water, and the insoluble precipitate collected, washed with alcohol, and dried in air.

Amidation of carboxylic acids with the amide of diphenylphosphinic acid. A mixture of 0.01 mole of the amide of diphenylphosphinic acid, 0.01 mole of carboxylic acid, and 5 ml of pyridine was boiled under reflux for 4 hours. The pyridine was removed in vacuum, and the residue treated with 20 ml of a 10% aqueous solution of ammonia; the diphenylphosphinic acid formed as a result of the reaction, and the unreacted carboxylic acid dissolved. The amide of the carboxylic acid was collected, washed, and, if necessary, recrystallized. The crude amides were usually quite pure, and melted 2-3° below the recrystallized samples. Acidification of the filtrate precipitated diphenylphosphinic acid, contaminated with the unreacted carboxylic acid. After recrystallization from alcohol, the diphenylphosphinic acid melted at 190-192° [6] and did not depress the melting point of authentic diphenylphosphinic acid. In this way, the following amides of carboxylic acids were obtained: benzamide (yield 31%, m.p. 130° [7]); p-nitrobenzamide (yield 87%, m.p. 198-200° [8]); o-nitrobenzamide (yield 72%, m.p. 175-176° [9]); m-nitrobenzamide (yield 66%, m.p. 140-141° [8]); 3,5-dinitrobenzamide (yield 84%, m.p. 182 to 183° [10]), and p-chlorobenzamide (yield 65%, m.p. 177-178° [8]).

In dioxane solution under the same conditions, the amidation of p-nitrobenzoic acid proceeded with 72% yield.

Amidation of carboxylic acids with dimethylamide of diphenylphosphinic acid. A mixture of 0.012 mole of the dimethylamide of diphenylphosphinic acid, 0.1 mole of carboxylic acid, and 5 ml of dioxane was boiled under reflux for 5 hours. The dioxane was removed in vacuum, and to the residue was added 10 ml of water and a few drops of hydrochloric acid; the unreacted dimethylamide of diphenylphosphinic acid was thus converted into diphenylphosphinic acid. Then a 10% aqueous solution of ammonia was added to the reaction mixture to an alkaline reaction; at this, the diphenylphosphinic acid and the unreacted carboxylic acid dissolved. The insoluble dimethylamide of the carboxylic acid was collected, washed, and recrystallized. In this way, we obtained the dimethylamide of p-nitrobenzoic acid (yield 60%, m.p. 97-98° [11]), and the dimethylamide of 3,5-dinitrobenzoic acid (yield 96%, m.p. 139-141°); the needles from alcohol were insoluble in ether and ligroine, soluble in boiling water, alcohol, benzene, and carbon tetrachloride, and readily soluble in cold acetone.

Found %: N 17.35, 17.20. $C_9H_9O_5N_3$.

Calculated %: N 17.57.

In pyridine solution under the same conditions, the amidation of p-nitrobenzoic acid proceeded with 41% yield.

SUMMARY

1. The amide and dimethylamide of diphenylphosphinic acid amidated carboxylic acids on heating in pyridine or dioxane, and were hydrolyzed very readily. The amide, dimethylamide, and phenylamide of diphenylthiophosphinic acid, and the phenylamide of diphenylphosphinic acid did not amidate carboxylic acids under the same conditions, and were hydrolyzed with difficulty.

2. The mechanism of the amidation of carboxylic acids by the amide and dimethylamide of diphenylphosphinic acid differed from that of the amidation of carboxylic acids by amides of sulfuric acid.

3. Some amides of diphenylphosphinic and diphenylthiophosphinic acids were prepared.

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SYNTHESIS OF ORGANOPHOSPHORUS COMPOUNDS
FROM HYDROCARBONS AND THEIR DERIVATIVES
XI. OXIDATIVE CHLOROPHOSPHINATION OF NITRILES

R. I. Bystrova, Yu. M. Zinov'ev and L. Z. Soborovskii

Original article submitted March 3, 1958

As a result of the oxidative chlorophosphination of hydrocarbons or their derivatives, a C—P bond is produced and acid chlorides of the corresponding alkanephosphinic acids are formed. The reaction was achieved with halogen-substituted paraffinic hydrocarbons and haloolefins. The oxidative chlorophosphination of alkoxy-substituted hydrocarbons, i.e., ethers, is also possible [1,2].

In the present work, we studied the reaction of phosphorus trichloride and oxygen with cyano-substituted paraffins (nitriles of carboxylic acids). During the process of the work, it was also found that the reported [3] inhibition by acetonitrile of oxidative chlorophosphination of hydrocarbons and the oxidation of phosphorus trichloride was explained by the presence of high-boiling impurities in the commercial reagent, whose nature was not established. It was found that pure, freshly distilled acetonitrile did not inhibit either the oxidative chlorophosphination of hydrocarbons or the oxidation of phosphorus trichloride into phosphorus oxychloride. The introduction of a very small amount of residue from distillation of the acetonitrile into the phosphorus trichloride led to practically complete inhibition of both of the reactions mentioned.

Together with this, we noted that, under the conditions which were used for oxidative chlorophosphination, the acetonitrile reacted with phosphorus trichloride and oxygen. The high-boiling (about 70° at 3 mm) substance thus formed had the character of an acid chloride. However, we were unable to isolate this compound in a pure form since on distillation it decomposed into phosphorus oxychloride and acetonitrile.

We attempted to convert the acid chloride obtained into the ethyl ester of the corresponding acid by reaction with alcohol. However, the reaction products yielded only triethyl phosphate and ammonium chloride. The formation of the latter was apparently due to a secondary reaction of acetonitrile with hydrogen chloride, formed by interaction of the acid chloride with alcohol.

More precise results were obtained in the reaction of phosphorus trichloride and oxygen with propionitrile. The compound isolated distilled without noticeable decomposition (80° at 3 mm). It had the character of an acid chloride and contained considerably more chlorine than that calculated for the acid chloride of cyanoethanephosphinic acid, $C_2H_4(CN)P(O)Cl_2$, whose formation might have been expected in this case, had the oxidative chlorophosphination of propionitrile proceeded by the scheme accepted for other substituted hydrocarbons.

$$C_nH_{2n+1}X + 2PCl_3 + O_2 \rightarrow C_nH_{2n}XPOCl_2 + POCl_3 + HCl \tag{1}$$

The nitrogen and phosphorus contents of the substance obtained were found to be low in comparison with the composition corresponding to the formula presented.

Analysis data of the substance were close to the values calculated for a compound with the formula $C_3H_5Cl_3ONP$, whose formation during the reaction with phosphorus trichloride and oxygen was possible only if liberation of hydrogen chloride did not occur. Evidently, this substance could have formed only if the $C \equiv N$ group was involved in the reaction.

$$C_2H_5C\equiv N + 2PCl_3 + O_2 \longrightarrow \underset{(I)}{C_2H_5CCl=NP(O)Cl_2} + POCl_3 \tag{2}$$
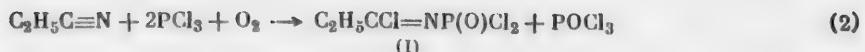
We also could not exclude the reaction course in which there first occurred the production of a C−P bond, characteristic of oxidative chlorophosphination.

$$CH_3CH_2C\equiv N + 2RCl_3 + O_2 \underset{CH_3CH(CN)P(O)Cl_2}{\overset{CH_2(CN)CH_2P(O)Cl_2}{\diagdown}} + POCl_3 + HCl$$
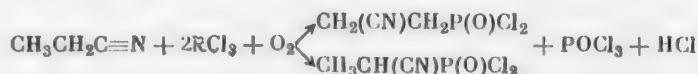
Then, the hydrogen chloride formed added to the nitrile group with the formation of compounds represented by Formulas (II) or (III).

$$\underset{(II)}{CH_2(CCl=NH)\cdot CH_2P(O)Cl_2} \qquad \underset{(III)}{CH_3CH(CCl=NH)P(O)Cl_2}$$

To establish the structure of the compound obtained, an investigation was made of its infrared absorption spectrum.* The spectrum showed bands close to those characteristic of C−Cl (769 and 1540 cm^{-1}), and C=N bonds (1640 cm^{-1}). At the same time, bands characteristic of C≡N, C−P, N−H, and C=O bonds were not observed. The data obtained made it possible to ascribe Formula (I) to the substance isolated, and to reject Formulas (II) and (III). The possibility of compounds of type (I) existing was confirmed by Kirsanov and Derkach, who recently described substances similar to that obtained by us [4].

To confirm the ideas presented above, we carried out the oxidative chlorophosphination of benzonitrile, a compound which could only undergo this reaction if the nitrile group was involved in the interaction, since it is known that benzene does not undergo oxidative chlorophosphination. We were able to isolate a product from the reaction of benzonitrile, phosphorus trichloride, and oxygen. The properties of the substance synthesized differed from those described by Kirsanov for the unstable trichlorophosphazobenzoyl, $C_6H_5CON=PCl_3$ [5], which was isomeric with this compound. The infrared spectrum of the substance showed characteristic bands of C=N and P=O bonds. The band of the C−O bond was absent. Thus, the compound obtained should be assigned the formula $C_6H_5CCl=NPOCl_2$. On distillation, the substance decomposed extremely readily with the evolution of phosphorus oxychloride. It should also be noted that the oxidative chlorophosphination of benzonitrile was readily inhibited by extremely small amounts of various substances, which made the execution of this reaction difficult.

The oxidative chlorophosphination of nitriles of carboxylic acids, having 4 and more carbon atoms in the molecule, led to the formation of acid chlorides of cyanoalkanephosphinic acids, compounds containing a C−P bond, i.e., the reaction proceeded by the usual scheme, analogous to that proposed previously for halogen derivatives of alkanes [1].

$$C_nH_{2n+1}CN + 2PCl_3 + O_2 \longrightarrow C_nH_{2n}CN\cdot P(O)Cl_2 + POCl_3 + HCl$$

The acid chlorides of cyanoalkanephosphinic acids formed boiled over relatively wide temperature ranges, and were mixtures of isomeric compounds differing in the relative position of the $POCl_2$ groups in the carbon chain. This hypothesis was confirmed by the results of analyses of various fractions of the acid chloride of cyanobutane-phosphinic acid, obtained by oxidative chlorophosphination of valeronitrile. The infrared spectrum showed intense bands corresponding to the C≡N bond (2300 cm^{-1}). Analogous results were obtained by reacting butyronitrile with phosphorus trichloride and oxygen.

Thus, for nitriles of carboxylic acids containing more than three C atoms, oxidative chlorophosphination proceeds according to Scheme (1), and for acetonitrile, propionitrile, and benzonitrile, according to Scheme (2), and leads to the formation of a P−N bond.

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* The spectroscopic investigation was carried out by N. P. Rodionova, S. S. Dubov, and V. V. Fedotova.

EXPERIMENTAL

Oxidative chlorophosphination of acetonitrile. a) Through a mixture of 130 g of freshly distilled aceto-
nitrile and 350 g of phosphorus trichloride at 20°, oxygen was passed until reaction ceased. The phosphorus oxy-
chloride formed was removed in vacuum at room temperature. The operation was repeated several times. The
residue from each operation was 2-4 g. The combined mass from a series of operations was vacuum distilled.
After several distillations, a substance was obtained boiling at 68-75° (3-4 mm). During each distillation, a trap
cooled to −78° collected a noticeable amount of phosphorus oxychloride. It was impossible to isolate an individual
compound. The heavy oil obtained (d 1.55-1.65) reacted vigorously with water. b) 7.5 g of the oil isolated was
added at −5° to 50 ml of anhydrous alcohol. After removal of the hydrogen chloride and excess alcohol in vacuum,
a substance with b.p. 70° (3 mm), d^{20}_4 1.076, n^{20}D 1.4075 distilled. The substance was soluble in water. It did not
contain chlorine or nitrogen, and had 71.6% of OC_2H_5.

Triethyl phosphate has b.p. 90° (10 mm), d^{20}_4 1.0695, n^{20}D 1.4075; OC_2H_5 74.2%.

From the residue and the condensate separated white crystals, which did not melt up to 230°.

Found %: Cl 66.0; N 25.68. NH_4Cl.

Calculated %: Cl 66.29; N 26.18.

Oxidative chlorophosphination of propionitrile. Through a mixture of 55.0 g (1.0 mole) of propionitrile,
and 400 g of PCl_3 (2.9 mole), oxygen was passed until reaction ceased. From the reaction mass we isolated 10.8 g
(5.2%, calculated on the nitrile taken) of a substance. It dissolved readily in water.

B.p. 78-80° (3 mm), d^{20}_4 1.4932, n^{20}D 1.4918.

Found %: Cl 50.5, 50.7; N 6.21, 6.29; P 15.22, 15.38. $C_3H_5ONPCl_3$.

Calculated %: Cl 51.25; N 6.72; P 14.86.

Oxidative chlorophosphination of benzonitrile. Through a mixture of 188 g (1.375 mole) of PCl_3 and 60 g
(0.585 mole) of benzonitrile, oxygen was passed until reaction ceased. The oxidation proceeded in the presence of
a few granules of benzoyl peroxide. After two distillations, 1.4 g of substance was isolated from the reaction mix-
ture.

B.p. 140-145° (2.5 mm), d^{20}_4 1.4973, n^{20}D 1.5850.

The substance described by Kirsanov, trichlorophosphazobenzoyl ($C_6H_5CO \cdot N = PCl_3$) had m.p. 60-61° [4].

Found %: Cl 41.53, 41.0; N 4.98, 4.94. $C_7H_5ONPCl_3$.

Calculated %: Cl 41.49; N 5.46.

Oxidative chlorophosphination of butyronitrile. Through a mixture of 250 g (1.82 mole) of PCl_3 and 37.7 g
(0.835 mole) of $CH_3CH_2CH_2CN$ at 15°, oxygen was passed until reaction ceased. After two distillations, 5.24 g
of substance was isolated from the reaction mixture.

B.p. 110-112° (1.5 mm), d^{20}_4 1.3998, n^{20}D 1.4903, MR_D 38.43; calc. 38.49.

Found %: C 26.10, 26.36; H 3.54, 3.66; Cl 37.87, 37.87; N 7.70, 7.41; P 16.40, 16.37. $C_4H_6ONPCl_2$.

Calculated %: C 25.81; H 3.25; N 7.53; Cl 38.13; P 16.65.

Boiling point of fraction at 3 mm	d^{20}	n^{20}	MR_D	Analysis				Fraction as percent of total amount
				C	H	Cl **	N	
135—138°	1.3497	1.4935	43.11	29.15	4.45	34.56	6.43	38.52
140—144	1.3417	1.4925	43.29	—	—	35.07	—	24.58
145—148	1.3394	1.4924	43.35	—	—	35.02	—	24.58
150—155	1.3458	1.4913	43.16	29.38	3.92	34.90	7.82	12.29

* The chlorine content, determined by Stepanov's method, did not differ from that found
by a normal argentometric titration of a sample treated with water.

<u>Oxidative chlorophosphination of valeronitrile.</u> Through a mixture of 21.0 g (0.25 mole) of valeronitrile, and 200 g (1.45 mole) of PCl_3 at 20°, oxygen was passed until reaction ceased. Two distillations of reaction mixture yielded 12.2 g of substance boiling at 135-155° (3 mm). The yield was 24.4%. The characteristics of the separate fractions are given in the table.*

SUMMARY

1. It was shown that oxidative chlorophosphination of nitriles may proceed in two directions. Nitriles of acids having 4 and more C atoms in the molecule form acid chlorides of cyanoalkanephosphinic acids, $C_nH_{2n}(CN)P(O)Cl_2$, i.e., compounds containing a C—P bond. The first members of the nitrile series (acetonitrile and propionitrile), and also benzonitrile, react with PCl_3 and O_2 to form compounds containing a P—N bond, i.e., derivatives of acid chlorides of imido-N-phosphoric acids, corresponding to the formula $RCCl = NP(O)Cl_2$.

2. The acid chlorides of cyanopropane- and cyanobutanephosphinic acids were synthesized.

3. We obtained two acid chlorides of imido-N-phosphoric acid with the probable structures $C_2H_5CCl = NP(O)Cl_2$ and $C_6H_5CCl = NP(O)Cl_2$.

4. The acid chloride of imido-N-phosphoric acid, formed from acetonitrile, could not be isolated in a pure form.

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*Calculated for $C_4H_8(CN)P(O)Cl_2$ in %: C 30.02; H 4.03; Cl 35.46; N 7.00. MR_D 43.11.

**Original Russian pagination. See C.B. translation.

SYNTHESIS OF THIAZOLIDONE DERIVATIVES OF BIOLOGICAL INTEREST

XII. THE EFFECT OF CERTAIN SUBSTITUENTS IN THE MOLECULES OF RHODANINE DERIVATIVES ON THE ULTRAVIOLET ABSORPTION SPECTRA

M. I. Ganitkevich and N. M. Turkevich

L'vov Medical Institute

Original article submitted May 6, 1958

In previous communications [1,2], we showed that rhodanine and its derivatives are characterized by two absorption bands, a thione band in the region of ~260 mμ and an amide band at ~295 mμ. The introduction of arylidene (and also cinnamylidene or furfurylidene) substituents into position 5 produces a K-band with a strongly expressed maximum in the region of ~385 mμ, while the maxima in the region of the thione band frequently disappear and sometimes the amide band does likewise. The introduction of methyl and carboxymethyl groups into position 3 basically changes [2,3] only the absorption intensity, above all in the first two bands. According to data in [4], the introduction of a phenyl group into position 3 involves the appearance of two weakly expressed narrow bands in the region of 220-230 mμ.

To study the effect of aryl groups in position 3 on the absorption spectra, we synthesized 3-p-ethoxyphenyl-rhodanine (I, $X = C_6H_4OC_2H_5$) and five of its derivatives substituted in position 5.
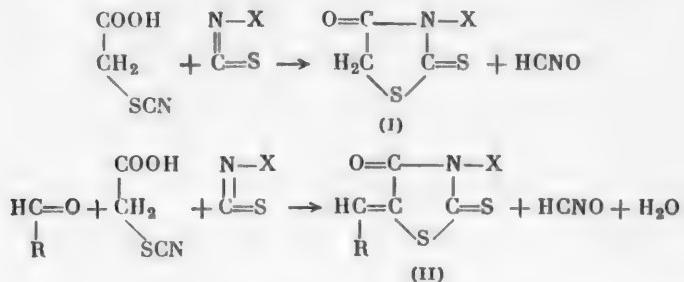
In the spectra of all the compounds obtained (Figs. 1-3), only inflections or weakly expressed maxima were observed in the thione band. The maxima in the region of the amide band were expressed more clearly, but in the presence of a K-band, they disappeared in certain cases (benzylidene and m-nitrobenzylidene derivatives).

Replacement of the phenyl group in position 3 by methyl led to a reduction in the absorption intensity, as is indicated by a comparison of the absorption curves of the ammonium salt of 5-benzylidene-3-p-carboxyphenyl-rhodanine (II, $R = C_6H_5$, $X = C_6H_4COONH_4$) (Fig. 2) and the ammonium salt of 5-benzylidenerhodanine-3-acetic acid [3] (II, $R = C_6H_5$, $X = CH_2COONH_4$). Analogous results were obtained by comparing the absorption curves of 3-p-ethoxyphenyl-5-benzylidenerhodanine (II, $R = C_6H_5$, $X = C_2H_5OC_6H_4$) (Fig. 1) and 3-methyl-5-benzylidene-rhodanine [3] (II, $R = C_6H_5$, $X = CH_3$).

Esterification of the carboxyl groups ($-CH_2COOH \rightarrow -CH_2COOC_2H_5$), like neutralization of the carboxyl groups with ammonia ($-CH_2COOH \rightarrow -CH_2COONH_4$) did not change the positions of the main maxima and minima. A certain change in the absorption intensity only of the thione, and also, the amide bands, was observed. Blocking

| Name of compound	Yield (in %)	Melting point	Analysis data (in %)	
			found	calculated
3-p-Ethoxyphenyl-5-m-nitrobenzylidene-rhodanine	83	227-228°	7.68 N 55.92 C 3.66 H	7.25 N 55.94 C 3.65 H
3-p-Ethoxyphenyl-5-p-anisylidenerhodanine	77	225-227	4.03 N 61.49 C 4.84 H	3.77 N 61.43 C 4.61 H
3-p-Ethoxyphenyl-5-cinnamylidenerhodanine	94	235-237	4.13 N 65.38 C 4.79 H	3.81 N 65.37 C 4.66 H
NH$_4$ salt of 3-p-carboxyphenyl-5-benzylidene-rhodanine	81	295-296 (decomp.)	7.88 N	7.82 N
3-Carbethoxymethyl-5-benzylidenerhodanine	57	122-123	5.04 N 54.04 C 4.39 H	4.56 N 54.70 C 4.26 H
3-Carbethoxymethyl-5-m-nitrobenzylidene-rhodanine	67	150 (decomp.)	8.94 N 47.33 C 3.53 H	7.95 N 47.72 C 3.43 H
3-Carbethoxymethyl-5-furfurylidene-rhodanine	41	85	5.42 N 48.14 C 4.03 H	4.71 N 48.47 C 3.73 H
3-Carbethoxymethyl-5-cinnamylidene-rhodanine	55	181-182	4.83 N 57.15 C 4.62 H	4.20 N 57.63 C 4.54 H
3-Methyl-5-p-nitrobenzylidenerhodanine	86.4	210-211	10.54 N 46.62 C 3.07 H	10.00 N 47.13 C 2.88 H
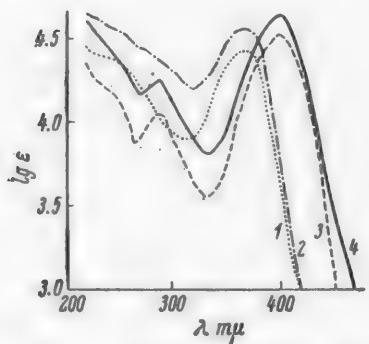
Fig. 1. Absorption spectrum curves: 1) 3-p-ethoxyphenylrhodanine; 2) ethyl ester of 5-benzylidenerhodanine-3-acetic acid; 3) 5-benzylidene--3-p-ethoxyphenylrhodanine; 4) 5-p--anisylidene-3-p-ethoxyphenylrho -danine.
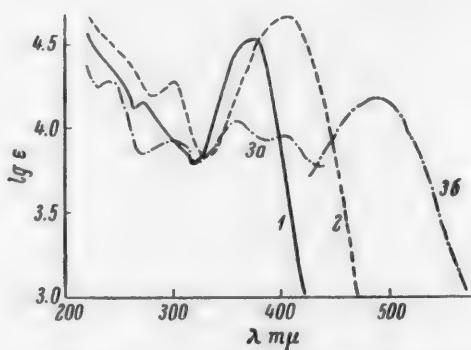

Fig. 2. Absorption spectrum curves: 1) ammonium salt of 5-benzylidene-3-p-carboxy-phenylrhodanine; 2) 5-cinnamylidene-3-p--ethoxyphenylrhodanine; 3a) 5-salicylidene-rhodanine-3-acetic acid in an alkaline solution (after 3 hours); 3b) the same in alkaline solution (after 10 minutes).
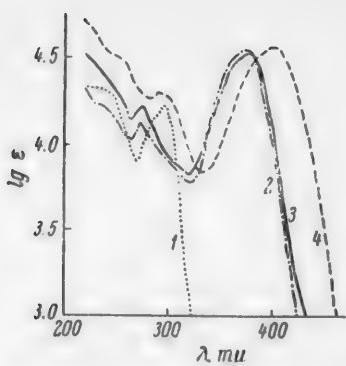
Fig. 3. Absorption spectrum curves:
1) ethyl ester of 5-m-nitrobenzyli-
denerhodanine-3-acetic acid; 2) 5-
-m-nitrobenzylidene-3-p-ethoxy-
phenylrhodanine; 3) ethyl ester of
5-furfurylidenerhodanine-3-acetic
acid; 4) 5-furfurylidene-3-p-ethoxy-
phenylrhodanine.
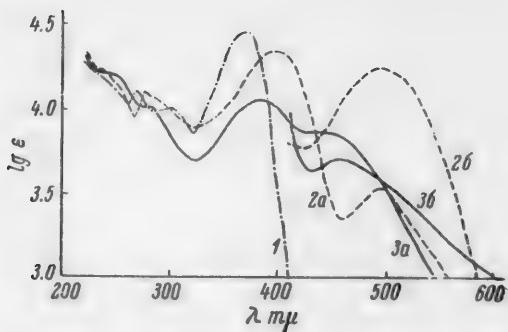
Fig. 4. Absorption spectrum curves: 1) 5-benzylidene-
-3-methylrhodanine in alkali solution; 2a) 5-salicyli-
dene-3-methylrhodanine in alkaline solution (after 3 hrs);
2b) 5-salicylidene-3-methylrhodanine in alkaline solu-
tion (after 10 min.); 3a) 5-p-nitrobenzylidene-3-
-methylrhodanine in alkaline solution (after 3 hrs); 3b)
5-p-nitrobenzylidene-3-methylrhodanine in alkaline
solution (after 10 min.).

the carboxyl groups also had hardly any effect on the K-chromophores (connected with the presence of arylidene groupings in position 5) and, due to this, the K-bands of the absorption were hardly changed (Figs. 1-3).

Interesting changes occurred as a result of the action of NaOH on 3-substituted derivatives of rhodanine, containing arylidene groups in position 5. The absorption spectra of 5-benzylidene-3-methylrhodanine (II, $X = CH_3$, $R = C_6H_5$) in alcoholic alkali solution (Fig. 4) were characterized by a considerable increase in the absorption intensity in the thione and amide bands in comparison with the spectra in neutral alcohol solution [3]. No essential changes in the K-band were observed, and, due to the stability of the preparation in alkaline solutions, the spectra did not change over a long period. Changes in the thione and amide bands were connected with a displacement of electrons under the action of NaOH, caused by eno-lization and salt formation. The probability of the formation of salt (III) was confirmed by the investigations of Holmberg [5], who isolated the sodium salt of 3-
-phenyl-2-ethoxy-2-mercaptothiazolidone-4, in a pure state, starting from 3-
-phenylrhodanine and sodium alcoholate.

(III)
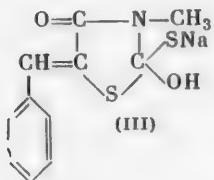
The appearance of new maxima for 3-phenylrhodanine under the action of alkali was observed by A. E. Lutskii [6]; however, this phenomenon could not be caused by enolization, since rhodanines unsubstituted in posi-tion 5 (including 3-phenylrhodanine) undergo hydrolysis under the action of alkalies, even in the cold, to form thioglycolic acid [7].

Essential changes under the action of alkalies were observed for 5-arylidene derivatives, which were capable of forming quinoid groupings due to the presence of OH or NO_2 groups in para or ortho positions. For the investi-gations we used 5-p-nitrobenzylidene-3-methylrhodanine (II, $X = CH_3$, $R = C_6H_4NO_2$), 5-salicylidene-3-methyl-rhodanine (II, $X = CH_3$, $R = C_6H_4OH$), and 5-salicylidenerhodanine-3-acetic acid (II, $X = CH_2COOH$, $R = C_6H_4OH$).

Freshly prepared alcoholic alkali solutions of 5-p-nitrobenzylidene-3-methylrhodanine had a pink color (ϵ 1000 at 595 mμ), but they became yellow in time (after 3 hours' standing, ϵ 1000 at 545 mμ). At the same time, neutral solutions of the preparation were almost colorless (ϵ 1000 at 430 mμ) [3]. In alkaline solution, there were characteristic inflections in the thione and amide bands (Fig. 4). The main maximum in the K-band (at 380 mμ) was partly displaced in comparison with that in neutral solution, and had a lower absorption intensity. This, and also the appearance of a new maximum at ~460 mμ, was connected with the formation of a new nitro-gen-containing K-chromophore. When alcoholic alkali solutions of the preparation were stored, this new maximum was displaced toward shorter wavelengths, and converted into an inflection.

Freshly prepared alcoholic alkali solutions of 5-salicylidene-3-methylrhodanine had a crimson color (ϵ 1000 at 585 mμ) and turned yellow in time (after 3 hours standing, ϵ 1000 at 555 mμ). Neutral solutions of the preparation were very weakly colored (ϵ 1000 at ~ 450 mμ). The new intense maximum (Fig. 4) at 498 mμ gradually became less intense.

Under the action of alkali on 5-salicylidenerhodanine-3-acetic acid, a new maximum appeared at ~496 mμ with the longwave absorption edge (ϵ 1000) at ~575 mμ (Fig. 3). The large changes in the absorption spectra not only in the thione and amide bands, but also in the K-band were connected with hydrolytic cleavage of the N_3—C_4 bond in the thiazolidine ring, which is characteristic of rhodanine-3-acetic acid. A negative nitroprusside test excluded the possibility of free mercaptide groups.

EXPERIMENTAL

3-p-Ethoxyphenylrhodanine and its 5-substituted derivatives were prepared by the procedure described by one of us [8], by the reaction of p-ethoxyphenyl mustard oil with thiocyanoacetates. For this purpose, 20 mmole of sodium-potassium thiocyanoacetate, 20 mmole of p-ethoxyphenyl mustard oil, and 1.0 g of lead acetate were heated with 15 ml of glacial acetic acid on a boiling water bath. In the synthesis of 5-substituted derivatives, during the condensation 20 mmole of the appropriate aldehyde was introduced simultaneously. When the evolution of carbon dioxide ceased (15-60 min), the reaction mixture was diluted with water, and the precipitate collected and recrystallized from glacial acetic acid or isoamyl alcohol. The melting points of 3-p-ethoxyphenylrhodanine (yield 76%) and its 5-benzylidene (yield 72%), and 5-furfurylidene derivatives (yield 85%) agreed with literature data for preparations obtained by Wagner [9]. In the table we present the substances not described in the literature.

3-p-Carboxyphenyl-5-benzylidenerhodanine was obtained by Pujari and Raut's method [10], and then converted into the ammonium salt by passing dry ammonia through an acetone solution of the preparation. The crystalline precipitate was collected, washed with acetone, and dried.

The esterification of rhodanine-3-acetic acid derivatives was carried out by dissolving the substance investigated in the least amount of boiling alcohol, and then passing dry HCl through the boiling solution for 30-35 minutes. The precipitate, which crystallized in the cold, was collected and recrystallized from ethanol.

The synthesis of 3-methylrhodanine derivatives was carried out by us previously [3].

The spectrophotometric investigations were carried out with a quartz SF-4 spectrophotometer. The light source was a low-voltage hydrogen arc lamp. Solutions of the investigated substances (concentration ~1 mg per 100 ml) were prepared in alcohol. For preparing alcoholic alkali solutions, 0.3 ml of 0.1 N NaOH was added to the alcohol, which corresponds to a seven- to nine-fold excess of alkali.

SUMMARY

1. The introduction of aryl or alkyl substituents (C_6H_5, p-$C_2H_5OC_6H_4$, CH_2COOH, $CH_2COOC_2H_5$, CH_2COONH_4, $C_6H_4COONH_4$) in position 3 of the rhodanine molecule, and its derivatives produced a displacement of electrons in the thione and amide groups, but had hardly any effect on the K-chromophores. An analogous effect was observed in the interaction of rhodanine with alkalies.

2. By the interaction of alkalies with 5-arylidenerhodanines, containing OH or NO_2 groups in the ortho or para positions in the arylidene grouping, an intense new absorption band in the 460-500 mμ region was produced.

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CATALYTIC CONVERSIONS OF TERPENES

## VIII. ISOMERIZATION CONVERSIONS OF TERPINOLENE IN THE PRESENCE OF TITANIC ACID

G. A. Rudakov and M. M. Shestaeva

Central Scientific Research Institute of Wood Chemistry

Original article submitted April 7, 1958

Isomerization conversions of monocyclic terpenes in the presence of acids are usually considered as irreversible processes, proceeding from a dipentene (I) through a terpinolene (II) to an α-terpinene (III) and a γ-terpinene (IV). On closer examination, these ideas are found to be implausible both from the point of view of the carbonium ion and ester mechanisms.

Actually, in the action of acids on terpinolene (II), one would expect the simultaneous formation of carbonium ions (V) and (VI) or the corresponding esters of α-terpineol and terpinen-4-ol, since C atoms 4 and 8 at the double bond in the terpinolene are equivalent. In the reverse elimination of a proton from (V), one would expect the formation of an equilibrium mixture consisting of 75% of dipentene (I) and 25% of terpinolene (II) [1], and in the reverse elimination of a proton from (VI), apparently, one should obtain an equilibrium mixture of hydrocarbons (III), (IV), and (II). In the light of these ideas, on heating any of the monocyclic terpenes listed above, with titanic acid, one would expect to obtain an equilibrium mixture of (I), (II), (III), and (IV).
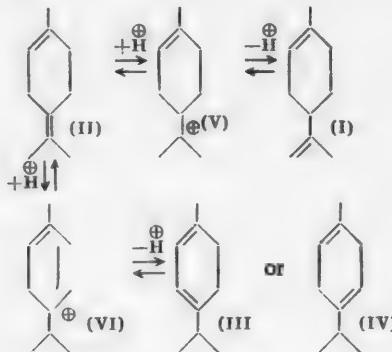

The aim of the present investigation was to establish whether the interconversion (I) $\rightleftharpoons$ (II) occurred, without considering whether the reversible conversion (II) $\rightleftharpoons$ (III) [or (IV)] was present. With this purpose, we studied the products obtained as a result of catalytic conversions of terpinolene (II) in the presence of titanic acid at 135°. It was found that, together with (II), (III), and (IV), they contained about 10% of dipentene (I), which confirmed the ideas presented on the presence of reversible conversions (I) $\rightleftharpoons$ (II). The catalyzate was also found to contain Δ^3-p-menthene and p-cymene, which indicated the presence of the parallel reaction of hydrogen disproportionation, even under the mild conditions described.

In the case when an optically active form of dipentene, limonene, was treated with the catalyst, the reversible conversions demonstrated by the present investigation led to its racemization.
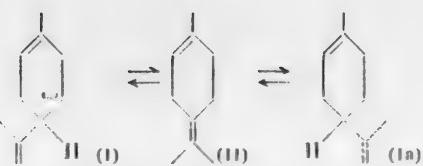
Up to now, it has been accepted that the racemization of limonene in the presence of acids proceeded only due to transposition of the double bond in the ring. It was supposed that the reaction proceeded through the terpene ester [2] or the corresponding carbonium ion (VII).
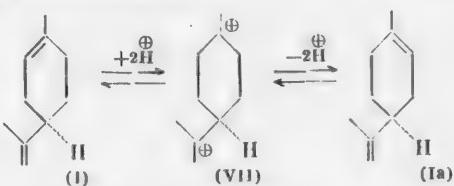
In solving the problem of which of the schemes presented was responsible for racemization of the bulk of the limonene, when heated with acids, it should be borne in mind that acids readily attack only the double bond in the isopropyl group, and that, under certain conditions, for example, in the absence of water, the double bond in the ring is not attacked at all. Therefore, the predominance of racemization of limonene due to the reversible conversions (I) $\rightleftharpoons$ (II) over racemization due to transposition of the double bond in the ring is probable, even in a homogeneous medium. As regards a heterogeneous medium, in this case, in addition to the considerations presented, it is necessary to take into account the orientation of the adsorbed limonene molecules on the catalyst surface. Since limonene (I) is very rapidly converted into terpinolene (II) when heated with solid acid catalysts, it may be considered that the isopropyl groups of the molecules are directed toward the catalyst. In this case, the addition of a proton at the double bond of the ring, which is not adjacent to the catalyst, may be difficult. Therefore, a considerable predominance of racemization of limonene due to the reversible conversions (I) $\rightleftharpoons$ (II) under heterogeneous catalysis conditions is most probable.

EXPERIMENTAL

As starting materials, we used titanic acid, characterized in our previous communications under the name of "catalyst 1-52" [3], and terpinolene (II), isolated from the mixture of products from the catalytic isomerization of α-pinene in the presence of titanic acid. In addition to terpinolene, the isomerizate contained unreacted α-pinene, camphene, limonene, and terpinenes. The isomerizate was vacuum distilled twice in succession on a column with an efficiency of about 25 theoretical plates. Since the isomerizate contained limonene ($[\alpha]_D + 68.8°$), the amount of this in the terpinolene fractions could be determined from the optical rotation with a high degree of accuracy (0.1%). Since the terpinolene obtained was completely free from traces of optically active substances, the presence of limonene (or its optically inactive form, dipentene, which boils at the same temperature) it was excluded. The purity of the terpinolene used is illustrated by the graph of the last distillation (Fig. 1).

The physical constants of the terpinolene used [$n^{20}D$ 1.4896, d^{20}_4 0.8596, MR_D 45.76; calc. 45.24; EMR_D 0.52 ($EMR_D = 0.5$ for the semicyclic double bond)] agreed well with its constants, presented in the latest works [4].

For the isomerization, 160 g of terpinolene was used. The reaction was carried out with vigorous stirring in the presence of 0.5% of catalyst for 85 minutes at 135°. Hydroquinone (0.01%) was added as an antioxidant.

The isomerizate ($n^{20}D$ 1.4904) was vacuum distilled. We obtained 78% of monoterpenes with $n^{20}D$ 1.4828 and d^{20}_4 0.8471, and also 22% of polymers with $n^{20}D$ 1.5200 and d^{20}_4 0.9205. The polymers were not examined further.

For separation of the α-terpinene, 22 g of maleic anhydride was added to 110 g of monoterpenes in 110 g of absolute ether at a temperature of not higher than +20° [5]. After two days, the product was washed twice with 350 ml of 5% aqueous NaOH solution, dried with potassium carbonate and metallic sodium, and again treated with 22 g of maleic anhydride under the same conditions. After three days, the ether solution was again washed with 5% NaOH solution and then steam distilled. The ether was distilled in vacuum from the ether extract collected (100 ml) and the terpenes vacuum distilled. We obtained 56.8 g of terpenes with $n^{20}D$ 1.4833 and d^{20}_4 0.8522.
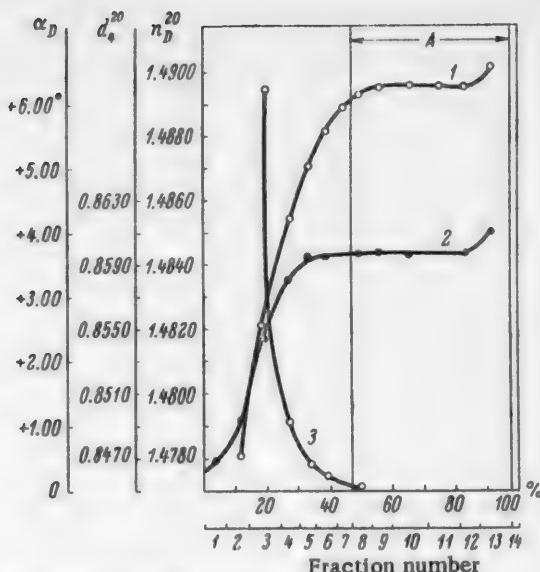
Fig. 1. Final distillation of the terpinolene fraction isolated from the isomerization products of α-pinene: 1) $n^{20}D$; 2) d^{20}_4; 3) α_D; A) fraction used for further isomerization.
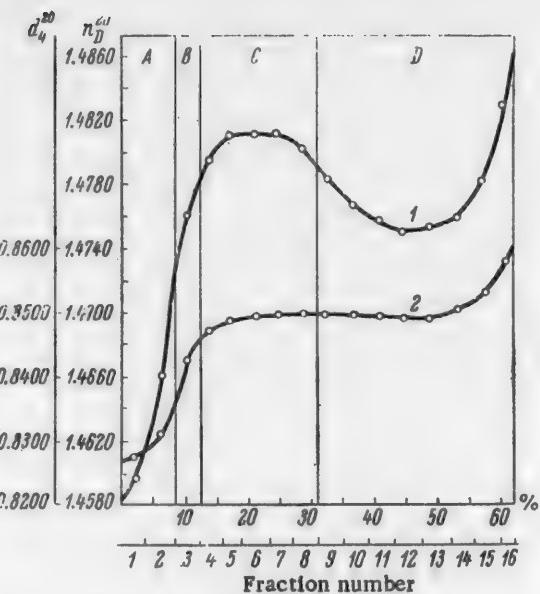
Fig. 2. Distillation of isomerizate obtained from terpinolene: 1) $n^{20}D$; 2) d^{20}_4.

The terpenes, freed from α-terpinene, were subjected to analytical distillations in vacuum on a column with an efficiency of about 50 theoretical plates. We distilled 62.5% of substance, and 37.5% remained in the residue. The results of the distillation are presented graphically (Fig. 2).

The distillation curves had a series of plateaus and inflections, on the basis of which the fractions obtained were separated into four groups designated by the letters A, B, C, and D in Fig. 2.

Group A (Fractions 1-2, 8.1%) was characterized by low specific gravity and refractive index. For Fraction 1 we found: b.p. 166°, $n^{20}D$ 1.4598 and d^{20}_4 0.8273. By titration with benzoyl hydroperoxide [6], it was established that there were 1.1 double bonds present per mole of hydrocarbon (taking M = 138), contained in the mixture of first and second fractions. Evidently, the fractions of this group contained, as the main component, Δ^3-p-menthene, which one of us had already found in analogous products, obtained in the catalysis of dipentene in the presence of an aluminosilicate catalyst [7]. The Δ^3-p-menthene was strongly contaminated by high-boiling products.

Group B contained Fraction 3 (3.9%). We considered this fraction as intermediate, and did not examine it.

Group C consisted of Fractions 4-8 (18.8%). The most characteristic fractions of this group, namely 5-7, had b.p. 177°, $n^{20}D$ 1.4811, d^{20}_4 0.8488, and consisted of dipentene and p-cymene. The presence of dipentene was proved by the preparation of its tetrabromide with m.p. 125°. After oxidation of the dipentene with 2% aqueous $KMnO_4$ solution, we isolated p-cymene ($n^{20}D$ 1.4910 and d^{20}_4 0.8613). From the p-cymene, we obtained p-hydroxyisopropylbenzoic acid with m.p. 156° [8]. Titration with benzoyl hydroperoxide established that the mixture of Fractions 4-8 contained 65% of dipentene (1.33 double bonds per mole of hydrocarbon) and 35% of p-cymene. The values of $n^{20}D$ (1.475) and d^{20}_4 (0.844), calculated by Biot and Arago's equation for the dipentene contained in Fractions 5-7, were found to be quite close to the constants generally accepted for dipentene [4,9].

Group D consisted of Fractions 9-16 (31.7%). Fraction 13, which was characteristic of this group (b.p. 182°, $n^{20}D$ 1.4752, d^{20}_4 0.8486) corresponded to γ-terpinene in its properties. Crystalline derivatives were not obtained from fractions of group D.

The residue from the distillation ($n^{20}D$ 1.495, d^{20}_4 0.862) contained terpinolene (tetrabromide with m.p. 116°), and some unidentified substances with a high refractive index.

SUMMARY

The conversion of limonene into terpinolene is a reversible reaction. This conversion apparently is the main reason for the racemization of limonene when the latter is heated with acid catalysts, especially with solid, limonene-insoluble catalysts of the titanic acid type.

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LETTER TO THE EDITOR

In an article we published [J. Gen. Chem. 26, 568 (1956)], we described the preparation and properties of dichloro- and trichlorophenyltrichlorosilanes. On repeating these syntheses with large amounts of materials, we established that the mixture of isomers of dichlorophenyltrichlorosilane boiled at 127-130° (10 mm) and had d^{20}_4 1.5522 and $n^{20}D$ 1.5652, and that trichlorophenyltrichlorosilane boiled at 112-115° (1 mm) and melted at 63-67°. On recrystallization from ether, the product had m.p. 67-69°.

In the experiments described, we used technical phenyltrichlorosilane, first distilled on a laboratory column, with b.p. 79° (10 mm), d^{20}_{20} 1.3265, $n^{20}D$ 1.5247; in experiments presented previously, the phenyltrichlorosilane was obtained in the laboratory by means of an organomagnesium synthesis from $SiCl_4$ and bromobenzene, and had b.p. 72-73° (7 mm), d^{20}_{20} 1.3151.

A. Ya. Yakubovich and G. V. Motsarev

* Original Russian pagination. See C.B. translation.

DISCUSSION

THE PROBLEM OF THE ORDER OF CHLOROARYLATION OF VINYLACETYLENE

A. A. Petrov, Kh. V. Bal'yan, Yu. I. Kheruze and T. V. Yakovleva

Lensoviet Technological Institute, Leningrad

Original article submitted July 16, 1958

The recently published article by A. V. Dombrovskii [1] confirmed data [2] indicating that vinylacetylene is only chloroarylated by diazonium salts at the ethylene bond (I). Although the experiments of one of us and A. T. Troshchenko [3] led to the same conclusion as regards the order of addition of diazomethane to vinylacetylene, the exclusive 1,2-addition of chlorine and aryl in this apparently radical process seems improbable to us.

Substance	Boiling point (pressure, in mm)	d^{20}_4	$n^{20}D$	Acetylene compounds found (in %)
Adducts (I) + (II) + (III)				
Sample A	87° (3)	1.0790	1.5643	79
Sample B	87° (3)	1.0798	1.5642	53
A. V. Dombrovskii's data [1]	105° (3)	1.0788	1.5641	—
Patent data [2]	68-69° (1.7)	—	1.5660 (31°)	—
Alcohols (IV) + (V)				
Our data	96.5-97° (3.5)	1.0498	1.5486	76
Literature data [5]	98° (2)	1.0490	1.5481	—
Chloride (VI)				
Our data	78° (3)	1.0903	1.5550	100
Literature data [5]	75° (2)	1.0970	1.5555	—
$C_6H_5-CH=CH-C\equiv CH$				
From adducts (I) + (II) + (III)	63-65° (2.5)	0.9816	1.6056	83
A. V. Dombrovskii's data [1]	62° (3)	0.9762	1.6062	—
From chloride (VI)	65-67° (3)	0.9784	1.6047	94
Literature data [5]	59° (2)	0.9640	1.6123	—

Many repetitions of experiments under the conditions proposed by A. V. Dombrovskii showed that the categoric conclusion of this author as regards the order of chloroarylation of vinylacetylene did not correspond to actual fact. In all cases, the chloroarylation proceeded with the formation of somewhat variable, but always considerable amounts of 1,4-products (20-40% of all adducts).

. We demonstrated this by analysis of the infrared spectra of the adducts. Together with the frequencies of a terminal acetylene group (2125 and 3290 cm^{-1}), the spectra contained an intense frequency at 1950 cm^{-1}, which could only be ascribed to the allene grouping of compound (II).
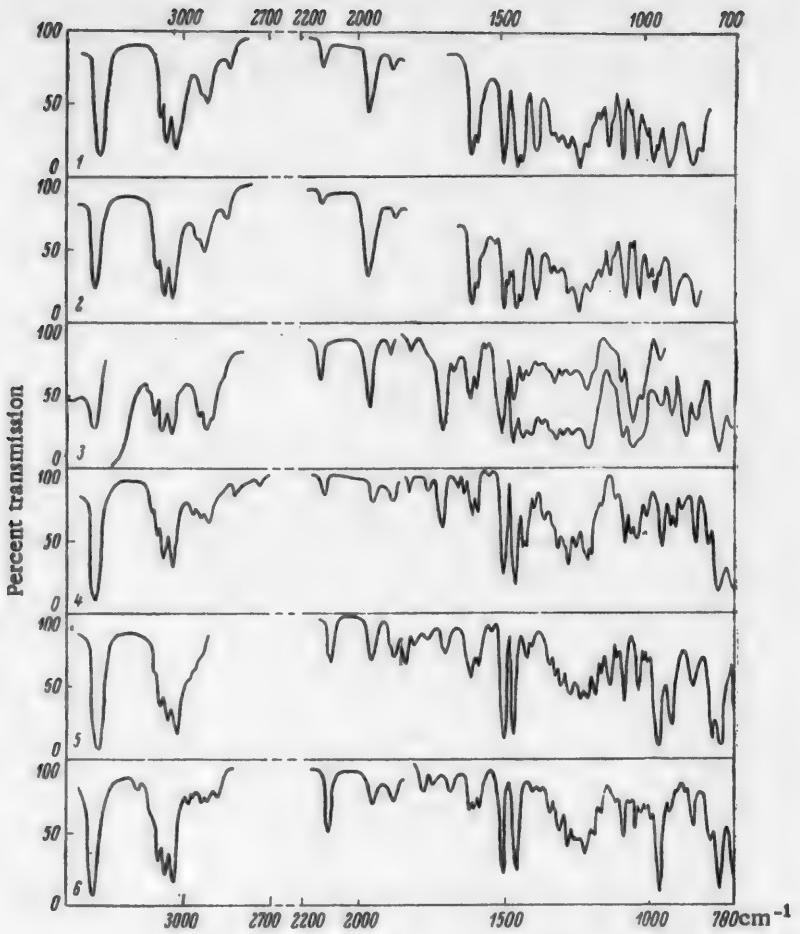
Infrared transmission spectra: 1) chloroarylation products – sample A;
2) the same – sample B; 3) mixture of alcohols (IV) and (V); 4) chlo-
ride (VI); 5) phenylvinylacetylene from the chloroarylation products;
6) the same – from chloride (VI).

$$C_6H_5-CH_2-CHCl-C\equiv CH, \quad C_6H_5-CH_2-CH=C=CHCl, \quad C_6H_5-CH=CCl-CH=CH_2.$$

$$(I) \qquad\qquad\qquad (II) \qquad\qquad\qquad (III)$$
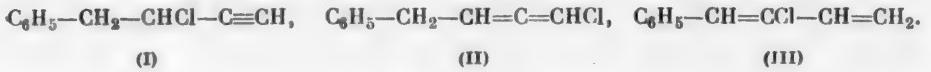
Determination of the acetylene adduct by the usual method [4] gave a higher content of it, the higher the
intensity of the acetylene grouping frequency in the spectrum of the sample, and the lower the intensity of the
frequency 1950 cm^{-1} (samples A and B).

Apparently, the chloroarylation products of vinylacetylene contained a very small amount of yet a third,
1,3-diene isomer (III), since the spectrum of the substance plotted in the region of 6100 cm^{-1} with a glass prism
had a small peak characteristic of the $CH_2=$ grouping.

Dehydrohalogenation of the chloroarylation products of vinylacetylene under the conditions presented in
A. V. Dombrovskii's article yielded phenylvinylacetylene containing approximately 20% of allene chloride with
a considerably less labile chlorine atom than the acetylene chloride (I). The samples of hydrocarbon usually con-
tained 3-7% of chlorine, and after a second treatment with alkali, about 1.5%. The infrared spectrum of the hy-
drocarbon had the intense frequency 1950 cm^{-1}, belonging to the chloride (II) present.

In order to prepare pure phenylvinylacetylene, we carried out a Reformatskii reaction with propargyl

bromide and benzaldehyde in the presence of zinc under the usual conditions [5], when it was found that, as in the case of aliphatic aldehydes [6], this reaction was accompanied by partial propargyl rearrangement and gave a mixture of approximately 80% acetylene (IV) and 20% allene (V) alcohols. However, the chloride (VI) obtained by the action of $SOCl_2$ on this mixture contained the allene chloride either in extremely small amounts, or not at all. The same could be said of the phenylvinylacetylene, which was obtained by dehydrohalogenation of chloride (VI).

$$C_6H_5-CHOH-CH_2-C\equiv CH, \quad C_6H_5-CHOH-CH=C=CH_2, \quad C_6H_5-CHCl-CH_2-C\equiv CH.$$
$$\text{(IV)} \qquad\qquad\qquad \text{(V)} \qquad\qquad\qquad \text{(VI)}$$
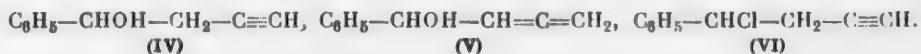
The experimental data we obtained are presented in the table and the figure. The infrared spectra were plotted on an IKS-14 spectrophotometer in the region up to 5μ with an LiF prism, and then with an NaCl prism. The layer thickness was 0.032 mm.

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*Original Russian pagination. See C.B. translation.